CITY AND COUNTY OF SAN FRANCISCO

A PREDESIGN REPORT ON

MARINE WASTE DISPOSAL

VOLUME IV

1973-1974 INVESTIGATIONS AND PRELIMINARY DESIGN

OCTOBER, 1975

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PREDESIGN REPORT ON MARINE WASTE DISPOSAL
1973-1974 INVESTIGATIONS AND PRELIMINARY DESIGN, VOLUMES IV AND V

In accordance with our agreement for engineering services dated February 9, 1973, we submit herewith the final report on our investigations made in 1973 and 1974 of the feasibility of marine wastewater disposal in the waters of the Pacific Ocean and of San Francisco Bay. It complements the work on this subject undertaken in 1969-1971 and hence is presented as Volumes IV and V of the Predesign Report on Marine Waste Disposal.

The results of the investigation show that it is feasible to dispose of sewage after secondary treatment, along with combined stormwater and sewage after chemically-augmented primary treatment, from the entire city either to San Francisco Bay near Islais Creek or to the ocean south of the San Francisco Bar. For disposal to the bay, the attainment of desired dilution criteria may, for short periods, not be possible because of constraints imposed by navigation and by salinity conditions during periods of high Delta outflow. For disposal to the ocean, the dilution criteria can be met at all times. Additionally, ocean disposal is preferable because it affords a greater degree of protection to marine organisms, less exposure of the public to effluent, greater reliability, and far less possibility that the city would, in the future, be required to construct additional treatment facilities to meet upgraded effluent requirements. We therefore recommend disposal of treated wastewater to the ocean through outfalls having diffusers designed to achieve safeguards for both the near-shore and the bottom waters.

For the dry weather flow we recommend construction of an ocean outfall having a capacity to carry the peak dry weather flow to an area southwest of the proposed treatment plant site having a water depth of 80 feet about 21,000 feet offshore. Total length of the outfall, including a 1,200 feet diffuser section would be about 23,000 feet and the internal diameter would be 7.5 feet.

For wet weather flow in excess of the capacity of the dry weather outfall, we recommend construction of a parallel ocean outfall having a capacity to carry approximately 800 mgd to an area having a depth of 50 feet about 8,000 feet offshore. Total length of the wet weather outfall including a 2,700 feet diffuser section would be about 11,000 feet and the internal diameter would be 13 feet.

Estimated construction cost for the two outfalls, based on July 1975 construction cost levels and including allowance for engineering and contingencies, is $61,400,000. During detailed design, consideration should be given to the merits of combining the parallel portions of the outfalls into a single structure or conduit.

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CHAPTER 1

INTRODUCTION

The City and County of San Francisco is presently engaged in a program to upgrade the treatment of its municipal wastewater. The problem in San Francisco is complicated by its combined system of sewers which receive both sewage and stormwater. One of the many phases of the planning concerns the alternative places and manner of final disposal of the treated wastewater and of the possible effect of such disposal upon the aquatic environment. Unlike other cities in the San Francisco Bay Area, San Francisco has the choice of disposing of wastewater either to the bay or to the ocean, or as it has historically done, to both bodies of water.

This report presents the findings of field and laboratory studies made in 1973 and 1974. These studies include: (1) ecological investigations in the vicinity of proposed discharge sites in the Gulf of the Farallones and San Francisco Bay; (2) a physical oceanographic survey of the proposed alternative ocean discharge sites; and (3) experiments testing the toxicity of effluents from alternative waste treatment processes on selected species of marine fishes and invertebrates with special emphasis on the eggs and larvae of the Dungeness crab. Conclusions drawn from the previous studies (Brown and Caldwell, 1971 and 1973) are incorporated in this report where they are relevant.

Prior Studies by San Francisco

In June 1969 the City and County of San Francisco engaged Brown and Caldwell to undertake a comprehensive engineering investigation of waste disposal both to the bay and to the ocean. That work culminated in volumes I and II of the "Predesign Report on Marine Waste Disposal" which were completed in September 1971, and are hereinafter referred to collectively as Brown and Caldwell 1971 or simply, the 1971 report. Additional work was undertaken in 1971-72 and reported in Volume III, dated April 1973.

The 1971 Report. The basic objectives of the 1971 report were: (1) to develop preliminary designs for submarine outfalls into the bay and the ocean for effluents from the North Point and the Richmond-Sunset Water Pollution Control Plants, and (2) to obtain information on submarine disposal sites to determine the degree of treatment required for intermittent wet weather flows originating in the northern and western parts of the city. The study included extensive investigations of the physical, oceanographic, and ecological conditions in the Gulf of the Farallones and San Francisco Bay waters adjacent to San Francisco. Design criteria and alternative plans for marine wastewater disposal were developed from the results of those investigations. The basic conclusion of the 1971 report was that primary effluent from the City and County of San Francisco, discharged at appropriate points through properly designed submarine diffusers, will not adversely affect the marine environment of the central bay or the Gulf of the Farallones.

The 1973 Report. Additional field and laboratory investigations were performed during 1971-1972 to supplement the work reported in 1971. The field studies were performed near the southern portion of the San Francisco Bar and included plankton tows to obtain information on the distribution of larvae of Dungeness crabs and other components of the zooplankton, and trapping surveys to further investigate the occurrence of adult Dungeness crabs. Laboratory studies were performed to determine the effects of primary effluent on the success of hatching of eggs of Dungeness crabs and effects on the resulting larvae.

Other Studies

In the decade prior to the 1971 report two important studies were completed which were referred to extensively during this study. The first was the "Comprehensive Study of San Francsico Bay" prepared for the State Water Resources Control Board by the Sanitary Engineering Research Laboratory of the University of California and published in seven volumes in 1965, 1966 and 1967. It contains a summary of the physical, chemical, hydrological and biological characteristics of the San Francisco Bay system.

The second study is the "San Francisco Bay-Delta Water Quality Control Program" completed in 1969 for the State Water Resources Control Board by a team of firms led by Kaiser Engineers. The report used the concept of relative toxicity as a principal water quality parameter and recommended a consolidated plan of wastewater interception from the entire area, treatment at a plant in San Mateo County, and disposal to the Pacific Ocean.

Subsequent to the Kaiser report, the state sponsored more detailed studies of the subregions of the bay area, including studies by the City and County of San Francisco. These, in turn, were used as the basis for a basin study, as required by Section 102 of Public Law 92-500, otherwise known as the 1972 Amendments to the Federal Water Pollution Control Act. The basin plan, completed in November 1974 and currently in process of adoption, is entitled "Water Quality Control Plan, San Francisco Bay Basin, California." It was prepared for the State Water Resources Control Board by a consortium of consulting engineers comprised of Brown and Caldwell, Water Resources Engineers, Inc., and Yoder, Trotter, Orlob and Associates. That study presents water quality objectives for both the ocean and bay waters, sets forth the degrees of treatment expected to be required, and presents a conceptual plan for partial consolidation of treatment facilities. More detailed facilities plans being considered by San Francisco are in conformance with the basin plan.

Changes in Disposal Requirements

Volume I of the 1971 report describes effluent quality and receiving water quality requirements previously set by the California Regional Water Quality Control Board, San Francisco Bay Region, for discharge to the bay and to the ocean. Subsequent federal legislation and changes in state policies have resulted in changes which are directly applicable to San Francisco.

The Federal Water Pollution Control Act Amendments of 1972 require that there shall be achieved for publicly-owned treatment works in existence on July 1, 1977 effluent limitations based upon secondary treatment. The Environmental Protection Agency (EPA) published the following required minimum levels of effluent quality corresponding to secondary treatment, in the Federal Register on August 17, 1973:

Constituent or characteristic	Requirement
Biochemical oxygen demand, suspended solids	(1) The arithmetic mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 30 milligrams per liter.
	(2) The arithmetic mean of the values for effluent samples collected in a period of seven consecutive days shall not exceed 45 milligrams per liter.
	(3) The arithmetic mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 15 percent of the arithmetic mean of the values for influent samples collected at approximately the same times during the same period (85 percent removal).
Fecal coliform bacteria	(1) The geometric mean of the value for effluent samples collected in a period of 30 consecutive days shall not exceed 200 per 100 milliliters.
	(2) The geometric mean of the values for effluent samples collected in a period of seven consecutive days shall not exceed 400 per 100 milliliters.
pH	The effluent values for pH shall remain within the limits of 6.0 to 9.0.

EPA acknowledged in that issue of the Federal Register that secondary treatment may not meet the percentage removal requirements for biochemical oxygen demand and suspended solids during wet weather at treatment plants which receive flows from combined sewers (sewers which are designed to transport both stormwater and sanitary sewage). EPA stated that for such treatment plants, the decision must be made on a case-by-case basis as to whether any attainable percentage removal level can be defined, and if so, what that level should be.

The State Water Resources Control Board adopted an ocean disposal plan in July 1972 which did not limit BOD but placed stringent limits on concentrations of heavy metals and other toxic substances, amounts of floatable matter and levels of other effluent characteristics applicable to ocean disposal. Specific limitations on effluent characteristics of the state ocean disposal plan have also been applied to estuaries, including San Francisco Bay. Although the state plan was established as a more realistic alternative for ocean disposal than the federal requirement for standard secondary treatment and disinfection, consideration of amending the federal act to permit substitution of the state plan has been indefinitely postponed. At this time both the state and federal requirements must be met.

The San Francisco Bay Basin Water Quality Control Plan includes among its objectives the opening of large portions of the bay to the taking of shellfish for human consumption. According to the National Shellfish Sanitation Program, this would require that the affected receiving waters meet a median coliform limit of 70 MPN per 100 ml and also meet all other requirements to minimize the hazard of bacterial contamination by sewage. Although requirements other than prohibition of discharge have not yet been adopted by the Regional Water Quality Control Board to permit such shellfish harvesting, a tentative requirement for a San Mateo County subregional study called for a median effluent coliform MPN not to exceed 2.2 per 100 ml and hence would require effluent filtration.

Objectives and Scope of Present Study

Following the completion of the studies made by Brown and Caldwell (1971, 1973) and based on the oceanographic data in the 1971 report, the subsequent selection of potential outfall sites for disposal of wastewater narrowed to an area located two miles south of the San Francisco Bar and between two and four miles offshore. For this reason, the California Department of Fish and Game (DFG), by a memorandum of September 1, 1972 to the Regional Water Quality Control Board (RWQCB), recommended that the city undertake further field investigations to obtain biological information about the proposed outfall site. In addition, DFG requested further testing of the potential toxic effects of effluents from San Francisco to selected species of fishes and invertebrates previously found to be sensitive to primary effluents from San Francisco (Brown and Caldwell, 1971). Special emphasis was to be placed on Dungeness crabs, their egg hatching success and the survival of their larvae.

Subsequent to the 1973 report, new federal requirements specified secondary treatment or its equivalent for both ocean and estuarine wastewater disposal. Since there were several treatment processes that could be used, the city engaged a consultant to conduct a pilot plant test program to determine which of the available processes would meet the new discharge requirements. Effluents from these pilot units were used as the test medium.

In addition to the foregoing work requested by DFG, other information for predesign purposes was needed by the city. For ocean disposal, physical oceanographic data covering the physical-chemical characteristics of the water column remained to be determined for the fall season at the proposed discharge site south of the bar. Further, studies by the city pointed to the use of the Southeast plant site for treatment of sewage from both the North Point and Southeast Service Areas. Discharge to the bay in the area of the existing outfall was anticipated as a first-stage, if not permanent, disposal scheme. Thus ecological background data at the Southeast disposal site were also sought.

Authorization. In December 1972 the city requested Brown and Caldwell to prepare a tentative work program for additional studies. That program was incorporated into an agreement dated February 9, 1973 and certified April 12, 1973. The scope of the work was later revised and the agreement amended under a certification date of December 13, 1973.

Objectives. The broad objectives of the 1973-74 study were four-fold. The first objective was to obtain physical oceanographic data in the fall season needed for siting and preliminary design of an outfall in the ocean south of the San Francisco Bar.

The second objective was to meet requirements of the Department of Fish and Game, acting through the Regional Water Quality Control Board, with respect to further investigation of the occurrence of both adult and juvenile Dungeness crabs and juvenile fishes in the vicinity of the proposed site, the benthic infaunal biota of that area, the toxicity of pilot plant effluents to selected species of fishes and invertebrates, including the hatching of Dungeness crab eggs and the survival of the resulting larvae (zoeae).

The third objective was to obtain baseline biological data in the area of immediate influence of an extended submarine outfall in the vicinity of the Southeast Water Pollution Control Plant. Insofar as practicable, these data were to be comparable to other data that had been obtained or were to be developed for the ocean disposal site. To supplement the field data, an extensive review of the literature was also to be made.

The fourth objective was to review and, as necessary, revise design criteria for marine disposal set forth in Volume I. This would include the development of preliminary design and performance data for both dry and wet weather outfalls.

Scope of Study. The scope of the study was initially set forth in the tentative work program incorporated in the agreement and in a series of tasks outlined by the agreement. A more detailed work program and schedule was submitted to the city on May 14, 1973 for review by its Technical Advisory Board. It was further revised in December 1973 and is set forth in five tasks as follows:

Task I. Toxicity of Wastewater Effluents

The toxicity studies comprised three subtasks. Subtasks IA and IB involved the testing of effluents from pilot plants at the Southeast Water Pollution Control Plant (WPCP). Subtask IC involved bioassays with primary effluent from both the Southeast and the North Point WPCP's, to be run concurrently with bioassay work undertaken there routinely.

Subtask 1A. Effect of Pilot Plant Effluents on Selected Marine Fishes and Invertebrates. The juveniles of three fish species, walleye surfperch, shiner surfperch and English sole, and one shrimp species, either the bay or the brokenback shrimp, were recommended for testing by the California Department of Fish and Game. Because walleye surfperch were not readily available, the program was limited to shiner surfperch, English sole, and bay shrimp. The testing period was extended to include testing of treated effluent from a mixture of North Point and Southeast sewage and to also include some chronic toxicity tests.

Subtask IB. Effects of Pilot Plant Effluents on Immature Stages of Dungeness Crab. This subtask included studies of; (1) hatching success of eggs and the incidence of terminal pre-zoeae, (2) acute (96-hour) toxicity to first-stage zoeae, and (3) chronic toxicity.

Subtask IC. Acute Toxicity of Unchlorinated Effluents from North Point and Southeast WPCP. Routine bioassays using threespine sticklebacks as the test organism were being performed on the chlorinated effluent. Because the chlorine residual masks the effect of any conservative toxicants which may be present, this task included parallel bioassays of samples taken prior to effluent chlorination.

Task II. Preliminary Study for Wastewater Disposal in San Francisco Bay

This program was intended to provide supplementary information on the feasibility of wastewater disposal to San Francisco Bay in the vicinity of Islais Creek near the site of the existing Southeast WPCP outfall. These data were intended to augment previous studies described in the 1971 report.

Subtask IIA. Preliminary Design of Wastewater Outfall. This subtask was originally undertaken to determine the location and length of a diffuser site suitable for discharge of the combined flow from the North Point and Southeast Service Areas. This was needed to select the location of stations for benthic sampling. It has been extended to include preliminary design and performance data for both dry weather and wet weather discharge for the entire city.

Subtasks IIB, C, D and E. Studies of Benthos Near Southeast WPCP. These included four quarterly surveys of benthic infaunal invertebrates over an area which may be influenced by an increased effluent discharge for the Southeast site. This was an expansion of the routine monitoring surveys conducted in that area since 1971. The task was further expanded to include benthic fish trawls, chemical analysis of sediments and of the more common fishes, and a literature review.

Subtask IIF. Dispersion of Wastewater Effluents in San Francisco Bay. Concurrent studies on basin planning included mathematical modeling of dispersion of pollutants in San Francisco Bay. This subtask was to include special runs of the model, if necessary, to specifically define the influence of discharges to the bay near Southeast WPCP.

Task III. Studies in the Vicinity of the Proposed Ocean Outfall

This task comprised both physical and biological studies in the vicinity of discharge sites south of the San Francisco Bar.

Subtask IIIA. Physical Oceanographic Study, Fall Season. Physical oceanographic data were collected during the fall in the vicinity of the proposed ocean discharge site. Two stations were selected to represent conditions at the inshore and offshore extremes of sites under consideration. Each station was occupied for a period of 25 hours. The study design provided for data collection as follows:

1. Hourly observations of temperature, salinity (as determined by conductivity), dissolved oxygen, and pH at the surface and at 10-ft depth intervals.

2. Hourly profiles of current direction and velocity at the surface and at 10-ft depth intervals.

3. Hourly observations of sea and weather conditions, including wind speed and direction, wave height and periods, prevailing swell direction, cloud cover, and air temperature.

4. Release of dye at daylight and mid-day for visual and photographic checks on mass movement of water surface.

Subtask IIB. Benthic Biological Surveys in the Vicinity of the Proposed Outfall. The biological survey comprised samplings during three seasons in the months of March, July, and October in a 30 square nautical mile area encompassing the preliminary outfall sites. Field work, as recommended by the Department of Fish and Game, and subsequent laboratory studies were as follows:

1. Crab trapping at 7 stations for adult Dungeness crabs.

2. Bottom trawls for fishes and invertebrates at 12 stations.

3. Sediment sampling and identification and enumeration of infaunal organisms at 22 stations.

4. Chemical analyses of organisms and sediments for organic pollutants and heavy metals.

Task IV. Revise and Develop Design Criteria for Disposal to Ocean and to Bay

This task comprised a review of previous design criteria and the development of new criteria based on the results of this study and new federal and state requirements. It included a comparison of the effects of discharge to the bay and to the ocean.

Task V. General Supervision and Preparation of Final Report

This task included all work not assignable to the other tasks, including general supervision of the study and preparation of the final report.

Advisory Boards

Two advisory boards were instituted by the city during the course of the prior study. These have been continued throughout the subsequent work including this present study and report. The Technical Advisory Board consisted of recognized authorities in the fields of environmental engineering, oceanography, and marine ecology. Serving as Chairman was Percy H. McGauhey, Professor Emeritus of Sanitary Engineering at the University of California at Berkeley. Other initial members were Dr. Pat Wilde, Professor of Oceanography at the University of California at Berkeley; Dr. Wheeler J. North, Professor of Marine Biology at the California Institue of Technology; Dr. Curtis L. Newcombe, Professor Emeritus of Biology at San Francisco State University. An additional member added to the staff in 1973 was Dr. Edmund Smith, Director of the University of the Pacific Marine Station at Dillon Beach. The members of this board have provided both individual and collective counsel and guidance throughout the conduct of the study and during the preparation of the report.

The second group, the Project Advisory Board, was composed of representatives of local, state, and federal agencies which are actively concerned with wastewater discharge to the bay or ocean. During the course of the present study the Project Advisory Board was not called to meet until a draft report was prepared. Representatives of the various agencies, however, were informally called upon during the work to advise on phases of the study falling within their particular scope of interest or expertise.

Information and Data Available to the Study

Full use was made of previous studies and reports prepared for the City and County of San Francisco and other local, state and federal agencies. The city also made available progress reports of other consultants, plant operating reports, and other current information necessary for coordination with other on-going phases of its water pollution control program.

Acknowledgments

Successful completion of a project of this type is dependent upon the advice and cooperation of many individuals and organizations. We are particularly indebted to Robert C. Levy, San Francisco City Engineer and his staff for their advice, assistance and decisions when needed. The direction and guidance of the city's Technical Advisory Board has been invaluable, and we wish to express our gratitude to each member.

We are also indebted to staff members of the California Department of Fish and Game for their counsel, assistance in the field, and review of data developed in the biological investigations; to the staffs of the Ichthyology and Invertebrate Zoology Departments of the California Academy of Sciences; to Steinhart Aquarium personnel, particularly Mr. Thomas Tucker for care and treatment of fishes and Dungeness crabs used in the toxicity testing program; to Mr. D.V. Buchanan, Oregon State University Marine Laboratory, Newport, Oregon, for assistance in the Dungeness crab toxicity bioassays; and to the staff of the Pacific Marine Station, University of the Pacific, Dillon Beach, California, particularly to Dr. J.A.Blake, for assistance in identifying the polychaete worms from the Gulf of the Farallones.

The collection, analysis, and interpretation of data upon which this report is based could not have been accomplished without the generous help of a large group of dedicated people. To all who have so willingly contributed their time and talents to the success of this study, we are indeed grateful.

CHAPTER 2

SUMMARY AND CONCLUSIONS

Field surveys, laboratory studies and data analyses were undertaken in 1973 and 1974 to provide the basis for evaluation of alternative sites for discharge of treated sanitary sewage of the City of San Francisco and evaluation of the possible effect of such disposal upon the aquatic environment. The report is summarized and conclusions are presented below.

PHYSICAL OCEANOGRAPHY OF THE PROPOSED OCEAN WASTEWATER DISPOSAL SITE

Oceanographic studies made in 1970 indicated that conditions critical to the design of an outfall that discharges at all times of the year occur in the fall season. Physical oceanographic studies were made in October 1973 near the previously recommended disposal site to provide data in the fall season needed to supplement those obtained in 1970 and reported in Volumes I and II.

1. The investigation consisted of obtaining water quality and current data at two stations located south of the San Francisco Bar. Station 1 was approximately two, and Station 2, four nautical miles offshore. At each station measurements were made over a 25-hour tidal day during a period of minimal tidal range. Measurements included hourly vertical profiles of temperature, specific conductivity, dissolved oxygen, pH and light transmittance and hourly profiles of current speed and direction. Releases of a dye tracer were made at one station to check water movement in the surface layer of the water.

2. Water density was observed to increase from the surface to the bottom throughout the tidal cycle. The smallest measured density gradient, the condition most conducive to the surfacing of effluent, occurred during a short flood at Station 2 and at the end of an ebb at Station 1.

3. During ebb flow, the upper layer has a higher temperature and lower salinity and density, and is relatively thick. During the flood current, incoming more dense water in the lower layer causes a thinner upper layer at a given location. The depth to the pycnocline ranged diurnally from 15 feet at both stations to 35 feet at the offshore station and 40 feet at the inshore station.

4. Dissolved oxygen concentrations measured in the upper layer of the water column varied considerably during the tidal cycle, while the concentration in the lower layer, beneath the pycnocline, remained relatively constant. Daytime supersaturation occurred in the upper layer and is strong evidence of photosynthetic activity of phytoplankton. Below the pycnocline, minimum dissolved oxygen concentrations were less than 4 mg/l at the offshore station and less than 5 mg/l at the inshore station.

5. The lowest turbidity, or greatest water clarity, was observed immediately below the pycnocline. This condition was most pronounced during each of the flood cycles when ocean water dominates the study area. During ebb periods depth of the more turbid upper layer increased due to outflow from San Francisco Bay, which has greater turbidity.

6. The net direction of flow at Station 2, furthest offshore, was directed away from the coast in all water layers. The net direction of flow at Station 1 was directed away from the coast in the upper layer, slightly offshore in the middle layer where the pycnocline occurred most often, and slightly to the east of north toward the Golden Gate in the lower layer.

7. Movement of surface water from Station 2 as tracked by observations of dye released at that station was consistent with current and wind data.

BENTHIC MARINE RESOURCES AT THE PROPOSED OCEAN DISPOSAL SITE

Field surveys were undertaken in a 30 square mile study area, centered on the proposed wastewater disposal site in the Gulf of the Farallones. The time span of the surveys was from July 1973 through April 1974. Three different sampling techniques were used to allow an evaluation of the species of animals which inhabit the study area: (1) a trawl net was used to sample the bottom fishes and invertebrates; (2) crab traps were used to sample adult Dungeness crab; and (3) a sampling dredge was used to collect samples of bottom material for analysis of the physical and chemical characteristics of the sediment and for identification and enumeration of invertebrate animals which live on and in the sediment.

1. Sediment samples were collected for physical and chemical analyses from 22 stations on surveys in October 1973 and February 1974. Particle size analyses on sediment samples revealed distinct patterns in the sediment composition. Sediments at stations in the southern section of the study area were composed primarily of silt and clay, whereas sediments at stations in the northeastern section and at stations at the San Francisco Bar were composed primarily of sand.

2. Sediments were analyzed for heavy metals (cadmium, copper, chromium, lead, mercury, nickel, and zinc) and chlorinated hydrocarbons. The results showed that the surface sediments in the study area were relatively uncontaminated. No distribution patterns were evident.

3. Trawls were made to sample benthic organisms from 12 stations on surveys in July and October 1973 and April 1974. The trawl surveys resulted in the collection of 48 species of fishes (100,100 specimens) and approximately 31 species of invertebrates (7,546 specimens).

4. The families of fishes having the highest numbers of species represented were the pleuronectids or right-eyed flatfishes (nine species), and the embiotocids, or surfperches (six species). Pleuronectids composed 28.0 percent of the total number of fishes caught (28,132 individuals) and 55.4 percent of the total weight of the catch (25,322 kg). Embiotocids made up 5.2 percent (5,037 individuals) by number and 1.9 percent (84.7 kg) by weight of the total catch, respectively.

5. Pacific tomcod, English sole, speckled sanddab, Pacific sanddab and white croaker were the five species of bottom fishes found to be numerically predominant.

6. Stations in the southwest portion of the study area contributed most to the total fish catch during the three surveys with regard to number of species, total number of fishes collected, and total weight of fishes collected.

7. Two species of fishes were found to be tumor-bearing: Pacific sanddab (one specimen) and English sole (64 specimens). In the comparison of the length-weight relationship curves of tumor-bearing and normal fishes, the normal fishes were heavier.

8. Most of the invertebrate species were represented by less than 100 individuals and were collected on only one or two surveys. The sand dollar, Dendraster excentricus, was the most abundant species collected but was found at only one station. The black spot shrimp, Crago nigromaculatus, was the most abundant species of Crago shrimp and the second most abundant invertebrate. The slender crab, Cancer gracilis, was the most abundant Cancer crab.

9. A total of 431 Dungeness crabs, Cancer magister, was collected. The examination of the catch data indicated that this species is distributed throughout the study area.

10. Concentrations of all metals except zinc, chromium, copper, and mercury were below the detection limit of 0.1 mg/kg wet weight for both fishes and crabs from both the October 1973 and April 1974 surveys. In crabs, chromium was found in only trace concentrations whereas zinc was very high, ranging from 26 to 49 mg/kg, as compared to the concentrations in fishes which ranged from 1.1 to 15 mg/kg. The concentrations of mercury and copper were generally low.

11. Crab trapping surveys were performed in July and October 1973 and February 1974. The majority of the crabs collected were Dungeness crabs, Cancer magister. Four other species of Cancer crabs and several miscellaneous species of fishes and other invertebrates were also collected.

12. Male Dungeness crabs, both legal and sublegal sizes, were found at all stations sampled on each survey. Relatively large numbers of female Dungeness crabs were collected in July 1973 and February 1974 catches, but not in October 1973, when these crabs bear eggs. Egg-bearing females generally are not caught in traps.

13. The average numbers of legal males collected per trap were 1.2 and 1.5 in October and February, respectively, which are both markedly lower than the 3.1 average obtained in July. The relatively low catch per trap of legal males in the February 1974 survey was probably the result of competitive fishing. A large number of commercial crab traps were observed in the study area during this time.

14. The red crab, Cancer productus, was the second most numerous species and was relatively abundant in October 1973, but not on the other cruises. Other crab species were poorly represented in the catches.

15. Samples of sediments were collected for identification and enumeration of benthic infauna from 22 stations on surveys in July and October, 1973 and February 1974. Approximately 150 species representing 11 phyla were identified.

16. A total of 16,287 organisms was collected. Of these, 8,482 were marine worms, 4,123 were gastropods or pelecypod mollusks, and 3,198 were crustaceans.

17. Relatively high numbers of species and individuals were found in the central portion of the survey area. Relatively low numbers of species and individuals were found at stations on and near the San Francisco Bar.

BENTHIC MARINE RESOURCES AT A PROPOSED BAY DISPOSAL SITE

Sediments were sampled for chemical analysis and identification and enumeration of organisms, and bottom trawls were made near the existing outfall from the Southeast Water Pollution Control Plant.

1. The City of San Francisco has monitored physical and chemical characteristics of sediments and kinds of organisms on and in the sediments quarterly since 1972 as part of a self-monitoring program for reporting to the Regional Water Quality Control Board. Sediments were sampled at these stations and at five additional stations as part of this study.

2. Previously collected data on particle sizes indicate that the sediments are predominantly silt-clay with a low sand fraction. An examination of a three-year record of data on concentrations of heavy metals showed no evidence of seasonal fluctuations or gross contamination. Oil and grease concentrations ranged up to 4,340 mg/kg but averaged well below 1,000 mg/kg. No patterns were observed in data on percent hydrocarbon and total sulfide.

3. Samples of sediments were collected for chemical analyses from 12 stations in February 1974. Concentrations of heavy metals were in the range observed in previous years and were generally low except for mercury.

4. Trawling surveys were made in December 1973 and March, May, and October 1974. Thirty-four species of fishes were collected: 17 in December 1973, 24 in March and May 1974, and 14 in October 1974.

5. The five most commonly collected species comprised 76.5 percent of the catch and were the northern anchovy, speckled sanddab, shiner surfperch, brown rockfish, and English sole.

6. The majority of the catch consisted of juvenile fishes. This was expected since San Francisco Bay is a known spawning and nursery ground for many of the species collected. A juvenile English sole was the only tumor-bearing specimen collected in this study area.

7. Approximately 14 species of benthic invertebrates were collected. Most species were represented by fewer than 50 individuals. Shrimp species of the genus Crago comprised 80 percent of the 716 specimens of arthropods collected. The bay shrimp, C. franciscorum, and the black tail shrimp, C. nigricauda were the two most commonly collected.

8. Fishes were analyzed for heavy metals and chlorinated hydrocarbons.

9. Samples of sediments were collected for identification and enumeration of benthic infaunal organisms from 12 stations quarterly from May 1973 through May 1974. Crustaceans comprised about 70 percent of the total organisms collected on each survey. The gammarid amphipods Ampelisca milleri, Corophium sp., C. ascherusicum , and Photis sp. were the numerically dominant crustacean species. The numerically dominant species of polychaete worms were Exogone lourei, Glycinde polygnatha, and an unidentified juvenile (Capitellid sp. or Mediomastus sp.). Mollusks, primarily Transennella tantilla, were also commonly collected.

10. A plot of total organisms for the three-year sampling period suggests that their numbers fluctuate seasonally with peak numbers occurring in winter and low numbers occurring in summer.

11. No significant relationship was found between distance from the existing outfall and total numbers of organisms, number of taxa, number of crustaceans, or number of mollusks collected at any one station.

TOXICITY STUDIES

Laboratory bioassay experiments were undertaken to determine the toxicity of treated effluents to marine organisms. The effluents were obtained from pilot plants which were constructed and operated under a separate program to test a variety of processes for treatment of the dry weather wastewater of San Francisco. The bioassay experiments thus were intended to assist both in process selections and in submarine outfall location and preliminary design. Concurrently the city conducted bioassays of untreated wet weather wastewater as part of its routine monitoring program.

1. The animals used to determine the toxicity of pilot plant effluents conformed with the special requirement of the California Department of Fish and Game. They had been found in prior studies to be sensitive to San Francisco effluent and were representative of local ocean and bay environments. The tests were made using juvenile English sole, adult shiner surfperch, adult bay shrimp, and the eggs and larvae of Dungeness crab. Three-spine stickleback were used for reference purposes and by the city in its separate monitoring program.

2. Pilot plant effluents tested were from two process series, and two wastewater sources identified and described as follows:

   a. Air activated sludge. Conventional primary treatment followed by diffused air activated sludge treatment.

b. Ferric chloride-flocculation. Ferric chloride flocculation and primary sedimentation followed by filtration and activated carbon sorption. The secondary filtration and sorption stage was not operated during the tests using crab eggs and larvae.

c. Pilot plant influent from the service area of the Southeast Water Pollution Control Plant. Only this influent was available during the test using crab eggs and larvae.

d. Pilot plant influent comprising a three to one mixture of wastewater respectively from the North Point and the Southeast service areas.

3. The results of 96-hour bioassays using fishes and shrimp showed no statistically significant toxicity in effluents from either the air activated sludge process or from the ferric chloride primary treatment plus activated carbon process. Effluent concentrations up to 100 percent effluent were tested with the salinity adjusted to a constant of 28 parts per thousand in the controls and in all effluent concentrations. Survival averaged 94.2, 98.9, and 81.0 percent using shiner surfperch, English sole and bay shrimp, respectively, in the undiluted air activated sludge effluents with a Southeast WPCP influent feed. Comparable averages for the ferric chloride flocculation and sedimentation effluents with activated carbon sorption were 87.5, 96.1, and 68.8 percent, respectively. With the North Point-Southeast WPCP mixture, the respective averages were 100, 95.7, and 83.3 percent in air activated sludge effluent; 100, 97.1, and 87.5 percent in ferric chloride flocculation and sedimentation effluent with activated carbon sorption; and 92.8, 99.3, and 73.5 percent in ferric chloride flocculation and sedimentation effluent without activated carbon sorption. Stickleback survival averaged nearly 100 percent in undiluted effluents from all processes tested irrespective of the influent feed.

4. Chi-square tests on experimental data on acute toxicity to fish and shrimp showed no significant correlation of survival and effluent concentration. Chronic toxicity tests were run for 12 and 23 days with effluent from both treatment processes using the Southeast WPCP and North Point-Southeast WPCP mixture as influent feeds, respectively. English sole exhibited no toxic response in the undiluted effluents from Southeast sources and survival was only slightly below that in the controls using the North Point-Southeast mixture. Shiner surfperch survival in the undiluted air activated sludge and ferric chloride flocculation and sedimentation effluents from Southeast sources averaged 25 and 45 percent, respectively, but the test fishes were infected with bacterial fin rot disease. No toxicity to shiner surfperch was found in the North Point-Southeast WPCP mixture.

5. Twelve 96-hour bioassays testing primary effluent from the existing North Point and Southeast treatment plants were conducted in 1973-74 using three-spine sticklebacks. These were made primarily to determine effluent toxicity prior to addition of chlorine to the effluent for disinfection. Bioassays conducted on samples having a chlorine residual of less than 0.1 milligram per liter (due to upstream chlorination for odor control) resulted in an average survival of 86 percent for the North Point plant and 19 percent for the Southeast plant.

6. Exposure of Dungeness crab eggs to a 50 percent concentration of effluent of the activated sludge pilot plant using wastewater from the Southeast

service area caused no statistically significant effect on the percentage of eggs which hatched to the larval stage during a 96-hour period. Salinity was adjusted to 25 parts per thousand.

7. Effluent from the ferric chloride primary treatment process was found to have some effect on the hatching success of crab eggs in 96-hour bioassays. Exposure of Dungeness crab eggs to a one percent concentration caused no statistically significant effect on the percentage of eggs which hatched to the larval stage. However, exposure to five and ten percent concentrations lowered the percentage of eggs which hatched to the larval stage in two of three sets of experiments. Average hatch to the larval stage in 50 percent effluent was 64 percent, as compared to 93 percent in the control.

8. Survival of first stage larvae of Dungeness crabs was not affected by exposure to activated sludge effluent for 96 hours at concentrations of 10, 20, and 50 percent. Survival was not affected by exposure to effluent of ferric chloride primary treatment at concentrations up to 20 percent. Exposure to a 50 percent concentration of effluent lowered the average survival to 32 percent as compared to 92 percent in the controls.

9. Swimming activity of first stage larvae of Dungeness crabs was reduced at the 50 percent concentration of effluents of the activated sludge process and of ferric chloride primary treatment.

10. Survival of first stage larvae of Dungeness crab was not affected by exposure to activated sludge effluent for periods of 15 and 25 days at concentrations of one, five, and ten percent. Survival after exposure to effluent of ferric chloride primary treatment for 15 days was 71 percent in a five percent concentration, as compared to 80 percent in the control. Survival after exposure for 25 days was 21 percent in the five percent concentration, versus 77 percent in the control.

11. One ninety-six hour test on primary effluent from the Southeast WPCP showed that this effluent was toxic to the first stage of larvae of Dungeness crabs at a concentration of 20 percent.

12. Between December 1972 and July 15, 1975, the city conducted 190 bioassays using the three-spine stickleback as test animals. These 96-hour bioassays were done to test the toxicity of untreated wastewater collected from overflow points in the sewer system during rainstorms. Average results were equivalent to 80 percent survival in undiluted wastewater and 100 percent survival occurred in more than one-half of the samples.

DESIGN CRITERIA AND ALTERNATIVE PLANS FOR MARINE DISPOSAL

Studies were made to review and evaluate governmental, biological, and oceanographic criteria for the siting and design of submarine outfall systems. Preliminary designs were developed for dry weather and wet weather effluents for alternative plans for disposal to the Pacific Ocean and/or to San Francisco Bay. Preliminary cost estimates were prepared. Performance of the outfalls was determined for peak design and average rates of flow and for the several oceanographic seasons.

1. The San Francisco Wastewater Master Plan proposes a system of interceptor and transfer pipelines to convey all dry and wet weather flow to a treatment plant site south of the San Francisco Zoo. All wastewater flows up to the peak dry weather flow of 215 mgd (million gallons per day) will be given secondary treatment by the activated sludge process and will be discharged continuously to the ocean through a dry weather outfall. During wet weather, flow in excess of secondary treatment plant capacity up to a total rate of 1,000 mgd will be treated by a chemically-augmented primary process and will be discharged intermittently through a wet weather outfall.

2. Alternatives to the proposed plan include for the outfalls (1) the recommended plan for discharge of all effluents to the ocean, (2) discharge of all effluents to the bay near the Southeast WPCP (Water Pollution Control Plant), and (3) discharge of dry weather flow from the North Point and Southeast service areas to the bay and of dry weather flow from Richmond-Sunset service area and all wet weather flow of the city to the ocean.

3. Wet weather flow will occur on the average about 300 hours per year. Most of this (92 percent) will occur between the beginning of November and the end of May when oceanographic conditions typical of the winter season prevail.

4. Proposed treatment is adequate for present and probable future requirements for discharge to the ocean. Further treatment requirements for disposal to the bay could require upgrading, such as effluent filtration, in the future. Based on a study of effluent dispersion using a mathematical model of the bay, nitrogen removal is not expected to be required for San Francisco wastewater.

5. Objectives and requirements of governmental agencies pertaining to marine disposal are found at several levels. The U.S. Corps of Engineers requires minimum vertical clearances of marine structures for protection of navigation and administers regulations on disposal of excavated bottom material.

6. Specific objectives and criteria with respect to shore zone protection, maximum toxicity concentration, initial dilution, and quality of the receiving water are contained in (1) State Water Quality Control Plan for Ocean Waters of California and (2) State Water Quality Policy for Enclosed Bays and Estuaries. The Water Quality Control Plan, San Francisco Bay Basin, incorporates and updates these objectives and criteria. It recommends as maximum a steady-state toxicity concentration of 0.03 toxicity units in the ocean and 0.04 units in most waters of the bay.

7. Permits under the U.S. National Pollution Discharge Elimination System have been issued by the state to the city for its water pollution control plants. The permit for the Richmond-Sunset plant is applicable to dry weather flow and

combines the federal requirements for secondary treatment with those of the state plan for ocean waters. Discharge of effluent is prohibited within 1,000 feet of the shore and where effluent will not receive a dilution of 100 to 1 as it reaches the surface.

8. Biological criteria historically have been based upon the results of short-term or acute bioassays using appropriate test organisms. A so-called safe or no effect concentration of a pollutant is estimated through the use of an application factor. This factor, a fractional multiplier applied to a concentration showing a statistically significant effect on the test organism, is based on judgement using available evidence on the relation between a safe level and a lethal level. This includes the effect of artificial conditions in laboratory tests, time of exposure in the natural environment, and nature of known toxicants including their persistence.

9. A three-step procedure for evaluating low-level toxicity is recommended in the Water Quality Control Plan, San Francisco Bay Basin. It is a review of measures for source control of toxicants and of treatment processes for toxicant removal, consideration of the results of bioassays and chemical analyses, and determination of the dominant toxicants and their characteristics, including persistence. Application factors recommended by the National Technical Advisory Committee to the Federal Water Pollution Control Administration generally range from 0.1 to 0.05 for nonpersistent pollutants and from 0.1 to 0.01 for persistent pollutants. The latter value is to be applied to the most persistent, such as chlorinated hydrocarbon pesticides. The factors are applied generally to the 96-hour TL_{50}, that is the concentration resulting in 50 percent survival in 96 hours.

10. Results of bioassays of activated sludge effluent showed essentially no statistically significant toxicity to any of the test organisms. If mortality in the controls is ignored, the computed maximum toxicity concentration is 0.75 determined with bay shrimp, 0.63 with crab egg hatching, and 0.56 with crab larvae. For the brief exposure during initial dilution an application factor of 0.1, resulting in a dilution ratio of 10 to 1, is conservative. Long-term or steady-state exposure in the ocean calls for a maximum toxicity concentration of 0.03 toxicity units. A dilution of 60 to 1 would result in a toxicity concentration of 0.01, based upon the crab experiments. The ocean plan requirement of an initial dilution of 100 to 1 at least 50 percent of the time, coupled with subsequent dispersion, would more than meet these biological criteria.

11. For discharge of activated sludge effluent to the bay, which has a steady-state limit of 0.04 toxicity units, a dilution of 75 to 1 would result in 0.01 toxicity units, based on the bay shrimp tests.

12. In developing application factors for wet weather discharge consideration must be given to the differences between wet and dry weather flows. These include (1) the intermittent nature of the discharge, (2) the lack of bioassays of treated wet weather effluent, and (3) the inverse relation between rate of flow and toxicity of wet weather wastewater.

13. Bioassay results significant to wet weather flow after chemically-augmented primary treatment included eight tests using fish, two using bay shrimp, and the tests with crab eggs and larvae. Also, the large number of tests of untreated wet weather overflow are important. Results of these tests show a

96-hour TL_{50} greater than 100 for all series except that for survival of crab larvae, which had a TL_{50} of 38. Toxicity concentration values ranged from less than 0.41 for English sole to 2.6 for crab larvae.

14. Review of pilot plant chemical analyses shows low toxicant values except for certain heavy metals. High variability is shown by high maximum values for those metals and indicates spills and dumps as a cause. The city has embarked on a strong source control program and is required to have effective control by mid-1976. The analyses reveal the principal difference in toxic pollutants between the pilot plant activated sludge effluent and the ferric chloride-augmented primary effluent. That difference is the presence of ammonia-nitrogen and surfactants in the ferric chloride-augmented primary effluent in an amount which could have an acute toxic effect in the low dilutions of effluent used in the bioassays.

15. Considering the limited frequency and duration of the treated wet weather discharge and the other evidence, an application factor of 0.10 is appropriate for short-time exposure. Applied to a TL_{50} of 38, an initial dilution ratio of 26 to 1 is indicated. For longer term intermittent exposure a dilution ratio of 100 to 1 would result in a toxicity concentration below the 0.03 level called for as a steady-state maximum in the ocean.

16. Oceanographic design criteria are based on information obtained in the 1970 and 1973 studies and field investigations. The 1970 study recommended an outfall location south of the San Francisco Bar pending further investigation in the fall season. Information obtained in October 1973 confirmed the feasibility of a site in that locality. It also showed that for the dry weather outfall a site near Station 2 was superior to the closer inshore Station 1.

17. A dry weather outfall should be designed to produce a near-surface submerged effluent field. The fall season is the most critical for that discharge. A wet weather outfall to the ocean should be designed to produce a surface field in order to obtain maximum seaward movement. The winter season is the most critical because of the predominance of wet weather flow at that period. A minimum depth of fifty feet is required for a wet weather outfall and diffuser to the ocean, and the diffuser should be at least one mile offshore to avoid the near-shore current which has a net bayward movement.

18. For discharge to the bay, a surface field or near-surface field is desirable for best seaward advection. It is also necessary to attain maximum initial dilution.

19. Design features will depend in part on results of boring and soils studies to determine foundation conditions. Pile support and bracing will be used where necessary for foundation stability. Joints will permit flexure to accommodate differential settlement and moderate transverse movement. Consideration should be given to special configuration or other design features to permit greater movement in the vicinity of the San Andreas Fault. Parallel sections of outfall may be laid as separate pipes or may be combined in a single structure.

20. Information presented in Volume I for use in preliminary cost estimates has been reviewed against recent submarine outfall contract costs. By adjustment to current construction cost levels it is suitable for present purposes.

21. Preliminary outfall designs are based both on mathematical models of diffuser performance in slack water and on the results of recent experimental work on outfall performance in a nonstratified current. The latter permits estimation of dilution under average conditions of effluent discharge and ocean current.

22. Under Alternative 1 the recommended dry weather outfall to the ocean is 23,200 feet long including a 1,240 foot diffuser section at a depth of 80 feet. Pipe diameter is 90 inches. Estimated cost is $29,500,000. The diffuser will produce a subsurface field in all seasons of the year. The field will be in the upper layer of the water column and during the critical fall season will provide dilution ranging from 100 to 1 at peak rate of flow to 150 to 1 at average flow and ocean current velocity of 0.32 knots. Subsequent dilution to 200 to 1 would occur within 2 nautical miles at average flow.

23. The recommended wet weather outfall will parallel the dry weather outfall for 8,400 feet and end in a diffuser section which would be 2,700 feet long. Pipe diameter would be 13 feet. The diffuser, at a depth of 50 feet, would be designed with a dual port system. Estimated construction cost is $31,900,000.

    The first port system would have ports sized to produce strongly rising plumes that would come to the surface under all conditions of density stratification. Initial dilution upon merger of the plumes would be 40 to 1. The second or alternative system of smaller ports would result in a near-surface submerged field during the winter season. Either of the systems could be used but not both at once. Estimated subsequent dispersion would result, in either case, in 100 to 1 dilution within four nautical miles down-current.

24. Alternative outfalls to the bay are constrained as to site by maritime activity including dredged channels and ship anchorage areas. A site north of the Islais Creek approach channel offshore and extending bayward from the existing southeast outfall would be suitable for a dry weather outfall. A similar but less desirable area south of the approach channel could be made suitable for a wet weather outfall.

25. The dry weather outfall would be 90 inches in diameter and 3,700 feet long including 2,700 feet of diffuser in 35 feet of water. Estimated construction cost is $4,8240,000.

    Performance at the design peak flow of 215 mgd would provide an initial dilution of 180 to 1 at an average current velocity of 0.6 knots. A dilution of 100 to 1 would be attained at slack water. Under conditions which may prevail for several weeks during a winter of high Delta outflow, the density structure pattern would cause an effluent field to form only a few feet above the bottom and it would have an initial dilution of about 50 to 1.

26. A wet weather outfall to the bay would be 13 feet in diameter and 3,800 feet long including a diffuser section 1,400 feet long. Estimated cost is $10,900,000. At peak wet weather flow of 785 mgd a surface field having an initial dilution of about 30 to 1 would form. For the high Delta outflow condition previously described, the effluent field at peak flow would reach stability near the bottom at a dilution of about 10 to 1.

27. Alternative 3 would require a 51 inch diameter dry weather outfall into the ocean to serve a peak flow of 65 mgd. The line would extend 22,000 feet to

the same diffuser site as in Alternative 1. The diffuser would be 375 feet long. Estimated construction cost is $17,600,000. Performance would be essentially the same as for Alternative 1. A 84-inch diameter outfall to serve a peak flow of 180 mgd would be constructed in the bay as in Alternative 2. Its length and performance would be similar to that for Alternative 2. Estimated cost is $4,400,000. The wet weather outfall to the ocean would be identifical to that for Alternative 1 except that the diffuser length would be reduced by about 100 feet. Construction cost and performance would be essentially the same as for Alternative 1.

COMPARISON OF ALTERNATIVE PLANS

The three alternative plans for submarine outfalls for the disposal of dry and wet weather effluents generally meet all design criteria. The submarine outfalls are only a part of the transport and treatment facilities involved in each alternative and hence their estimated construction cost must be combined with other costs before comparisons can be made on a cost basis. Factors which cannot be reduced to a cost basis include differences between the plans with respect to protection afforded to marine organisms and for public health, risk of damage to an outfall, and the possibility of changes in disposal requirements.

1. Marine organisms are shielded most from effects of effluent, good or bad, by minimizing their exposure. Alternative 1, with disposal to the ocean, does this through near-surface or surface fields which are advected seaward and which will not contact the shoreline. Alternatives 2 and 3, involving disposal to the bay, do not provide an equal degree of protection.

2. Public health is likewise best served by effluent disposal which minimizes exposure of people and of food sources which may act as disease vectors. Compared to the ocean waters which could be affected by effluent disposal, the waters of the bay are more intensively used by people and contain edible species of shellfish.

3. Risk of damage to the ocean outfalls is primarily that of a large movement along the San Andreas Fault. For the outfalls into the bay, the principal risk is of damage from maritime traffic including such activities as anchor dragging. The probable frequency of damage is greater for Alternatives 2 and 3 than for Alternative 1.

4. Requirements for treatment and disposal of wastewater have historically been upgraded from time to time. The possibility of future upgrading for disposal to the bay is substantially greater than for disposal to the ocean.

5. In final summary, Alternative 1, with discharge of all effluent to the ocean, is superior to those which provide for disposal to the bay and is the recommended plan.

CHAPTER 3

PHYSICAL OCEANOGRAPHY

This chapter summarizes physical oceanographic conditions measured in the Gulf of the Farallones during previous studies in 1970 and supplementary studies conducted on October 1-4, 1973. The 1970 studies also included the waters of San Francisco Bay adjacent to the city. Reference is made to Volume I (Brown and Caldwell, 1971) for the findings in that area.

An understanding of local conditions and their variation is essential for evaluating possible sites for and developing the design of submarine outfalls for San Francisco. Physical oceanographic variables which significantly affect the initial and subsequent dilution of effluent discharged from a submerged outfall include the vertical ambient density structure at the discharge site, currents, and mass water movement. The density structure of the receiving waters, as compared to the density of discharged effluent, controls the maximum rise of the effluent plume and affects the initial dilution achieved. Ocean currents likewise affect initial dilution and turbulence significantly affects subsequent dilution of the effluent field.

THE STUDY AREA

The general area of interest is that contained within the Gulf of the Farallones immediately west of the City of San Francisco. For the purpose of these studies, the Gulf of the Farallones is defined as that portion of the Pacific Ocean which extends from Bolinas Peninsula on the north to Pt. Montara on the south, and from the Golden Gate to the Southeast Farallon Islands. This area covers about 600 square miles and includes most of the continental shelf west of the Golden Gate. Water depth varies from a minimum of 23 ft over the bar seaward of the Golden Gate to a maximum of 300 ft north of the Farallon Islands. The bottom slope breaks sharply downward to the immediate west of the Farallon Islands, and within a few miles reaches depths of 10,000 ft.

The climate of the area within the Gulf of the Farallones is typical of the marine climate of other northern California nearshore coastal areas and is characterized by three seasons. During the winter rainy season, lasting approximately from November to April, maximum flow of fresh water from the land occurs and the northerly flowing Davidson Current interposes itself between the coast and the southerly flowing California Current. The summer fog season, lasting from about May through August, is characterized by declining upland flow to the ocean and the absence of the Davidson Current. The California Current also moves closer to shore and nearshore nutrient concentrations increase due to local upwelling of cold bottom waters. The third season is in the fall, lasting from September to the first rains (usually in November), and is characterized by minimum runoff, cessation of upwelling and coastal fog, and by the offshore flow of the California Current. These seasonal changes result in seasonal fluctuations of the physical-chemical characteristics of waters within the Gulf of the Farallones and also within San Francisco Bay.

The area of the Gulf investigated in 1970 comprised that portion which is most strongly influenced by the tidal ebb and flow from San Francisco Bay. This area is bounded on the west by a line drawn in an arc from Rocky Point on the north to the anchorage of the former San Francisco Lightship and then south to Mussel Rock. It also included studies within San Francisco Bay adjacent to San Francisco.

In 1973, oceanographic field studies were made in an area south of the San Francisco Bar and 2 to 4 miles offshore at Stations 1 and 2, Fig. 3-1.

OBJECTIVES AND SCOPE OF STUDIES

The initial objective of the oceanographic studies undertaken in 1970 was to define the characteristics of the coastal waters adjacent to San Francisco, both in the bay and in the ocean, as necessary for the preliminary design of submarine outfalls. The outfalls were to provide for the disposal of effluents from the existing North Point and Richmond-Sunset Water Pollution Control Plants and for the disposal of combined sewage and wet weather surface drainage from the northwestern portion of the city. This objective was subsequently expanded to include the preliminary design of outfalls to the ocean for disposal of the treated dry weather flow and the treated wet weather flow for the entire city.

The objective of the 1973 oceanographic study was to supplement the 1970 field work with respect to data obtained during the fall season in the area south of the San Francisco Bar.

Scope of the studies in each case was concerned both with those characteristics which directly affect submarine outfall siting and design and those which affect the marine environment independently of the presence of waste discharges. The scope of the 1970 study encompassed all three oceanic periods and included definition of mass water movements and of current regimens in specific areas, determination of water density versus depth and of dissolved oxygen and water clarity, observations of surface drift, and the definition of dispersion coefficients. The latter is a quantitative measure of mixing which results from water turbulence. Special studies were conducted to determine the exchange of ocean and bay water at the Golden Gate and to determine the performance of existing submarine outfalls.

During the conduct of the 1970 field work, the area within the San Francisco Bar south of the shipping channel (Fig. 3-1) was tentatively considered as a prime location for an ocean outfall. Hence Stations A and B were occupied during the fall period studies. Subsequent analyses of all factors revealed that the area south of the bar at a water depth of 70 to 80 ft was to be preferred, particularly for outfalls serving more than the western slope of the city. South of the bar the mass water movements had been observed in all three seasons. Physical-chemical data and current movements at Station 98 and density data at four other points southward almost to Point San Pedro had been obtained in the winter season. In the summer season, Station Y was occupied for physical measurements and single profiles were made at six other positions, each about one nautical mile distant from Station Y. Two dispersion coefficient tests and three surface drift tests were also made at Station Y.

The supplemental 1973 study was conducted to obtain information at Stations 1 and 2 (Fig. 3-1) during the fall season. Measurements included water temperature, salinity, dissolved oxygen, water clarity, and current direction and speed. Information concerning dispersion and surface drift obtained in 1970 was considered adequate

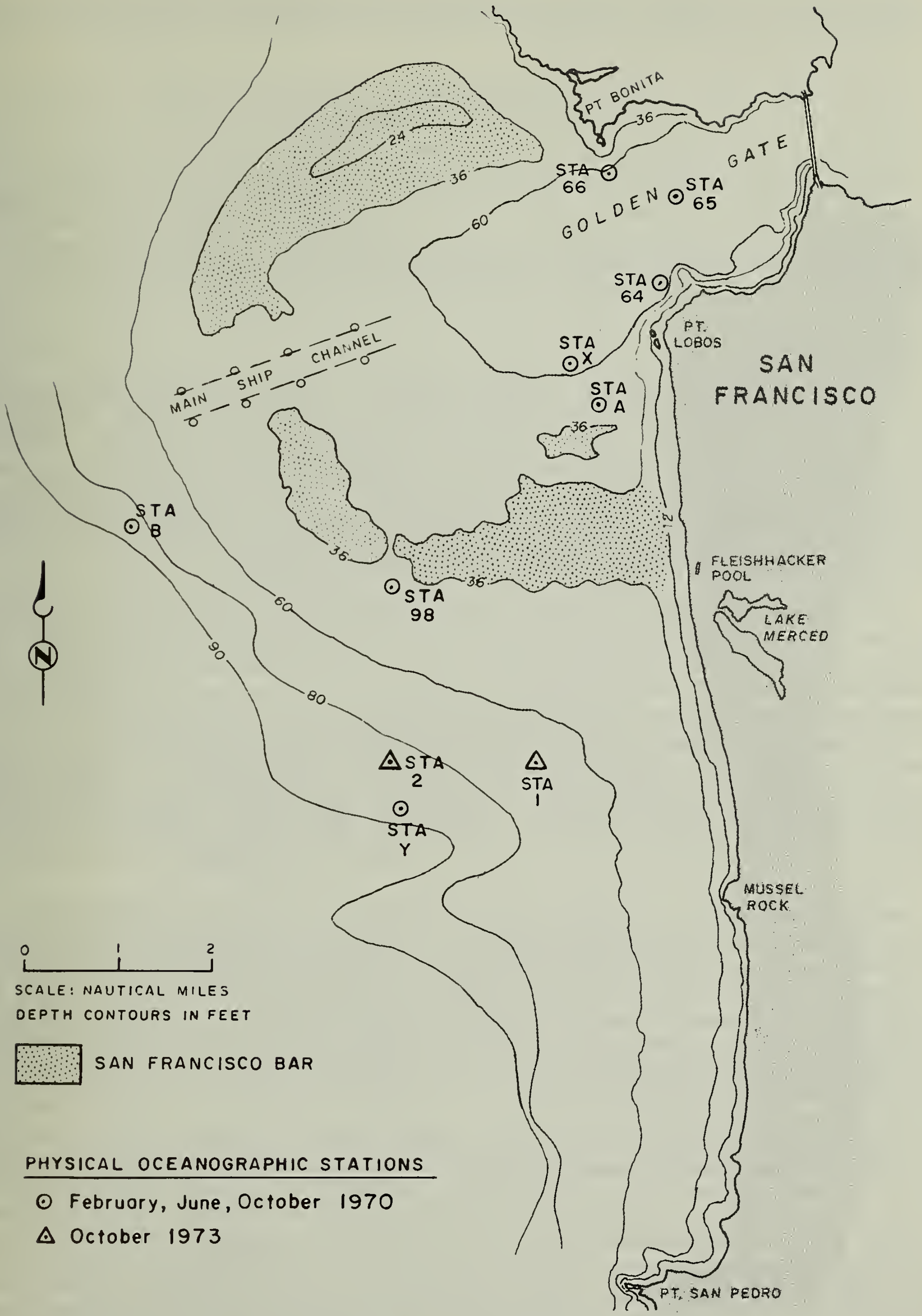


Fig. 3-1. Location of Physical Oceanographic Sampling Stations

for all seasons. However, two dye releases were made and the movement of the resulting dye patches were tracked.

DATA COLLECTION METHODS

Data collection methods used in the 1969-71 oceanographic study were discussed in detail by Brown and Caldwell (1971). This section includes only a brief discussion of the earlier methods, but presents a thorough discussion of the methods used in the 1973 study. The positions of all pertinent stations occupied during the 1970 and 1973 surveys are shown in Fig. 3-1.

The 1970 Study

Physical oceanographic surveys were conducted in February, June, and October of 1970 in order to define conditions over the three oceanographic seasons. The general movement of surface water masses was determined by aerial photography. Previous reconnaissance flights in a light plane during the fall of 1969 indicated that the movement of more turbid water out of San Francisco Bay and into the ocean could be tracked visually and photographically by recording the changing position of the advancing turbidity front. The 1970 aerial photographic program was very successful in recording the characteristics of mass surface water movement.

Information on changes in the water mass with depth was further provided by vertical profiles of temperature and salinity that were recorded on the research vessel. Temperature and salinity were measured with a Martek Model TDC system, and dissolved oxygen with a Martek Model DOA dissolved oxygen monitor. The probes for temperature, conductivity and dissolved oxygen, together with a probe for depth measurement, were enclosed in a perforated plastic housing and attached to a multiconductor underwater cable which was connected to instruments on the deck of the research vessel. The housing and probes were lowered by an electric winch to the desired depth, usually at 5 to 10 ft increments, and readings were then recorded. Water clarity was measured by Secchi disc, and wind direction and speed were periodically measured with a hand-held anemometer and compass.

A principal source of current data for the 1970 study was data collected by the United States Coast and Geodetic Survey in San Francisco Bay and in the Gulf of the Farallones during 1952, 1953 and 1954. In addition to the USC&GS data, current measurements were taken during the study by the following methods. A number of surface current measurements were based on the rate of movement of turbidity lines as recorded by photographs during the study of mass water movement. Other surface current measurements were derived from the shift in position of dye patches during the measurement of dye dispersion.

Measurements of subsurface currents were made by two different current measuring devices. The first current meter used for subsurface data was a Hydro Products meter which, when anchored in place at the depth desired, continuously recorded current direction and velocity. Four of these meters were lost in high seas during the second cruise. The current metering system employed for the remainder of the study was a TSK type E-2 captive electric current meter with a deck readout of current direction and speed, water temperature, and instrument depth. The TSK meter was lowered by winch from an anchored boat, with current measurements taken at the desired depths. Because of the complicated current regimen which exists in certain areas around the

Golden Gate, the more detailed current profiles obtainable with the captive meter provided information superior to that obtainable with meters anchored at one depth.

Surface drift measurements in the 1970 study were based on the surface drift of milk bottle caps released in batches of 1500 at specific locations. Milk bottle caps are waxed cardboard discs which float at the water surface with an extremely small area exposed to wind action above the surface. They were easily visible on beaches and were available in a wide variety of printed patterns so that identification of release points and times could be recorded.

Surface drift surveys using milk bottle caps were conducted in June and October, 1970. In January, 1971 the collision of two Standard Oil tankers near the Golden Gate Bridge resulted in the release of several hundred thousand gallons of heavy fuel oil in the Golden Gate and Central Bay, providing additional information on the movement of floatable materials in the Central Bay and Gulf of the Farallones and onto their shores. Shortly after the spill occurred, the Environmental Protection Agency arranged for three overflights of the slick area on successive days to record the position of the slick by infrared and ultraviolet remote sensing techniques.

Dispersion studies were conducted in the 1970 oceanographic study to define horizontal and vertical dispersion coefficients for the Gulf of the Farallones and the Central San Francisco Bay. The calculation of dispersion coefficients was based upon the natural dispersion of a quantity of red fluorescent dye (Rhodamine WT) dropped in an area where a surface effluent field might logically be discharged. Dye concentrations in the spreading dye field were measured with a Turner Model III continuous-flow recording fluorometer.

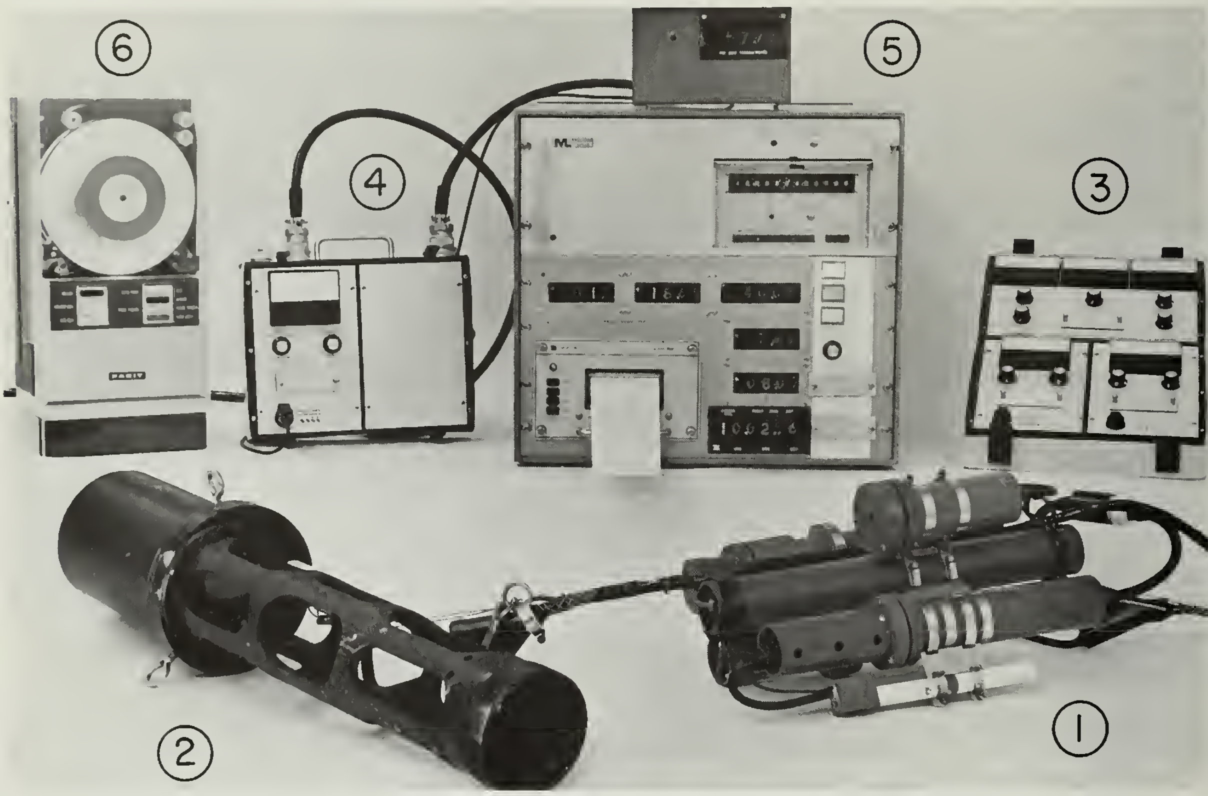
The 1973 Study

The 1973 field surveys to determine physical oceanographic conditions at Stations 1 and 2 (Fig. 3-1) within the Gulf of the Farallones were conducted on October 2 - 3 and October 3 - 4, respectively. These surveys were timed to take place in the fall season during tidal conditions least favorable for ocean disposal of wastewater effluent. The Alert, a 125-foot former Coast Guard cutter converted to oceanographic use, was employed as the research vessel.

Each station was occupied for a complete tidal cycle of 25 hours, during which vertical profiles of temperature, conductivity, dissolved oxygen, pH, and light transmittance were obtained generally every half hour between the surface and bottom using the water quality analyzer and transmissometer shown in Fig. 3-2. The sensors, described in Table 3-1, were mounted together as a single unit that was hand-lowered at a slow, uniform rate of about one-third foot per second by means of the electrical cable that connects to the deck readout unit. The readout simultaneously digitized all five parameters with depth and displayed the data, printed it and produced a computer-compatible tape. Periodically throughout the survey, surface water samples were collected during the profile measurements for determination of dissolved oxygen concentration by Winkler titration. These results were used to check the calibration of the dissolved oxygen sensor. Samples were also collected for subsequent laboratory determinations of salinity to check the calibration of the conductivity meter.

The physical-chemical data stored on field-punched tapes were used in a computer program which calculated water salinity from the conductivity data and water density from the temperature data and salinity calculation. In addition, the computer program produced depth-profile plots of each physical-chemical parameter on an X-Y plotter. Due to motion of the Alert from sea swells, vertical motions faster

than the response time of the sensors caused cyclic errors in the physical-chemical data. These errors were eliminated by visual smoothing during tracing of the machine-plotted data.



OCEANOGRAPHIC WATER QUALITY DATA ACQUISITION SYSTEM

1. Martek Mark III Underwater Sensors
2. Martek XMS Transmissometer
3. Martek Mark III Water Quality Analyzer
4. Martek Transmissometer Deck Unit
5. Digital Data Processor
6. Facit Paper Tape Punch

Fig. 3-2. Oceanographic Water Quality Data Acquisition System

Vertical profiles of current speed and direction were obtained hourly at depth increments of 10 ft or less using a Bendix Q-15 ducted current meter. The current speed detected by this meter is corrected for oscillation due to wave motion so that only net horizontal current speed is measured. The current meter is oriented in the direction of the net current flow by a 10-ft long vane, and azimuth is referenced to magnetic north by a compass contained within the current meter housing. The current meter was lowered to each successive depth for a period of approximately five minutes while both speed and direction data were recorded on a continuous chart recorder. Current direction data subsequently were corrected to true north and summarized for 20-degree segments. Mean velocities were defined for three vertical layers of water: upper (3 to 10 ft depth), middle (20 to 30 ft depth), and lower (50 to 60 ft depth).

Aerial observations of turbidity patterns were attempted on October 3 and 4 but were not successful because of limited visibility.

Table 3-1. Parameters Measured During Physical Oceanographic Survey

Parameter	Method of measurement	Accuracy	Indicating and recording methods
Current speed and direction	Ducted current meter	± 0.03 kt and ± 5 deg	Analog chart paper recorder
Dissolved oxygen[a]	Auto-temperature compensated polarographic gold/silver electrode	± 1% full scale, ± 0.2 ppm	Digital, printed paper tape ASCII coded Mylar tape
Turbidity, light transmittance	1-m path length transmissometer	± 1% full scale	Digital, printed paper tape ASCII coded Mylar tape
Specific electrical conductivity	Five-electrode guarded Kelvin cell	± 0.02 millimho/cm	Digital, printed paper tape ASCII coded Mylar tape
Temperature[b]	Transistor probe	± 0.1 C ± 0.01 C resolution	Digital, printed paper tape ASCII coded Mylar tape
Depth	Pressure transducer	± 1% full scale, ± 1 foot	Digital, printed paper tape ASCII coded Mylar tape
pH	Glass and silver/silver chloride electrodes	± 0.1 pH unit ± 0.01 unit resolution	Digital, printed paper tape ASCII coded Mylar tape

[a] Calibrated during survey using Winkler titration procedure.

[b] Temperature measuring systems are checked for accuracy with N.B.S. calibrated thermometers.

Surface water movements in the vicinity of Station 2 were measured by using a 40-percent solution of Rhodamine-B dye, adjusted to seawater density, as a tracer. The dye solution was released in undiluted five-pound units directly to the water surface at Station 2 during a short flooding tide (from a higher low water to higher high water) in the mid-afternoon of October 3, 1973, and tracked visually using an auxiliary survey vessel and a small aircraft. Locations of the dye patches were determined using radar on the Alert to obtain range and azimuth to either the auxiliary vessel or the aircraft as it passed over the center of the patch. There were two separate releases of dye approximately one and one-quarter hours apart. The initial dye patch was reinforced with additional tracer approximately two hours after release when the dye in the patch became difficult to distinguish visually from the background. Because of slow vertical dispersion during the period of observation, the patch should be considered as representative of only the surface of the water.

Quantitative measurements of dye concentration within the patch were not made during this investigation. Tracking was unfortunately limited to only a few hours in the late afternoon as a result of a low fog layer that was present in the early afternoon.

RESULTS

Physical oceanographic surveys in the Gulf of the Farallones in 1970 were conducted when oceanographic conditions were representative of the three oceanic seasons characteristic of the central California coast: February (winter conditions), June (summer conditions) and October (fall conditions).

Cruises during the Davidson Current period, in February, were planned to provide two periods of continuous observations over a complete tidal cycle. The first cruise, carried out on February 3-4, 1970, covered a period of maximum tidal amplitude and inequality. The second cruise on February 24-25, 1970 covered a period of equal tides of minimum amplitude.

Oceanographic investigations during the dry summer season when upwelling was occurring were made during four days of continuous boatwork from June 16 through June 19, 1970. The primary purpose of the February cruises had been to define general characteristics of the entire study area. The June cruise was planned to give more detailed attention to two specific areas where outfall diffusers might be located: an area inside the bar (Station X) and the other outside the bar to the south (Station Y). Station X was situated in about 60 ft of water 1.2 nautical miles west of Point Lobos, and Station Y was set in 85 ft of water approximately 2.5 nautical miles south of the bar and 3.5 miles offshore. All physical oceanographic work during the June cruise was oriented toward these two stations.

The fall cruises of 1970 were made during the week of October 5-11 and were completed before the first rain of the season. Physical oceanographic work was oriented about Station A within the bar and Station B west of the bar. Several factors combined to indicate that from the standpoint of wastewater effluent disposal in the Gulf of the Farallones, this is probably the most critical period of the year. Principal among these factors are:

1. Climatic conditions are most suited to recreational use of the ocean waters. Air and water temperatures are at the annual high and the strongly westerly winds of the summer season have subsided.

2. Water clarity is greatest at this season of the year, which means that esthetic objections to discoloration by an effluent field are more likely to occur during the fall season.

3. Freshwater outflow from the San Francisco Bay system is at the annual low, which in turn has two effects: (a) density gradients within the zone of influence of the bay outflow are at their annual low values, and (b) seaward displacement of the surface layer, which is greatest at maximum freshwater outflow, will be at a minimum.

As previously discussed, the 1973 oceanographic cruise was scheduled with respect to season and tide to measure representative conditions least favorable for ocean disposal at Stations 1 and 2 and was made during October 2-4. For the purpose

of completeness and organization, the results of this survey and the 1970 surveys are discussed below. However, since the results of the 1970 study were thoroughly discussed by Brown and Caldwell (1971), only summaries of those results are presented.

Mass Water Movement

Information obtained through aerial photography during each of the three seasons are presented in Volume I in detail. That information, supplemented by measurements of the physical-chemical characteristics of the water mass, presents a clear picture of mass water movement. Movement of surface water is shown schematically in Fig. 3-3. As there indicated, the ebbing tide from San Francisco Bay moves strongly westward and southward. During the months of high freshwater outflow, the water mass is strongly layered, and the surface ebb lasts longer than the flood. During maximum freshwater outflow, the surface layer may ebb continuously.

The distance which the surface mass moves westward and southward is a function of tidal amplitude and degree of layering. With maximum tidal amplitude and freshwater outflow, the bulk of surface outflow may reach westward almost to the Farallon Islands and southward past Point San Pedro.

During the summer and fall months, the ebbing tide may move through the area inside the main bar in an almost completely mixed condition. After crossing the bar where the depth is about 30 ft, however, the ebbing water spreads as a surface layer. Even under conditions of minimum tidal amplitude and minimum freshwater outflow, the ebbing tide will reach southward to Lake Merced and westward to the main shipping channel through the bar. Rarely does the ebb travel northward of the north bar under any conditions.

Once the ebbing surface layer has reached its maximum excursion, it moves comparatively little until moved along by the next ebb. Water which enters the bay on the flood tide comes primarily from the near-shore areas north and south of the Golden Gate. During the winter, this pattern also results in the inflow of dense, saline water near the bottom at the same time that less saline water is ebbing on the surface. In the summer and fall months, currents are usually in phase on the surface and at depth, but during the flood, bottom currents are stronger and during the ebb surface currents are stronger. These factors combined to produce a high rate of tidal exchange in the Golden Gate, particularly when the freshwater outflow is high.

After the surface layer has been displaced westward and southward to the limit of tidal influence, it disperses into the oceanic water mass. Within about 24 hours after it leaves the bay, it is no longer identifiable as a separate water mass. From that point its movement is presumed to be controlled by the prevailing oceanic currents.

Physical-Chemical Characteristics

Physical-chemical characteristics include temperature and salinity, which together determine density, and dissolved oxygen, pH, and clarity.

1970 Studies. Seasonal phenomena exert major influences on the physical-chemical characteristics of the waters within the Gulf of the Farallones during the winter months. Temperature stratification is minimal but freshwater outflow from the San Francisco Bay drainage is at its annual high. Because of its density and

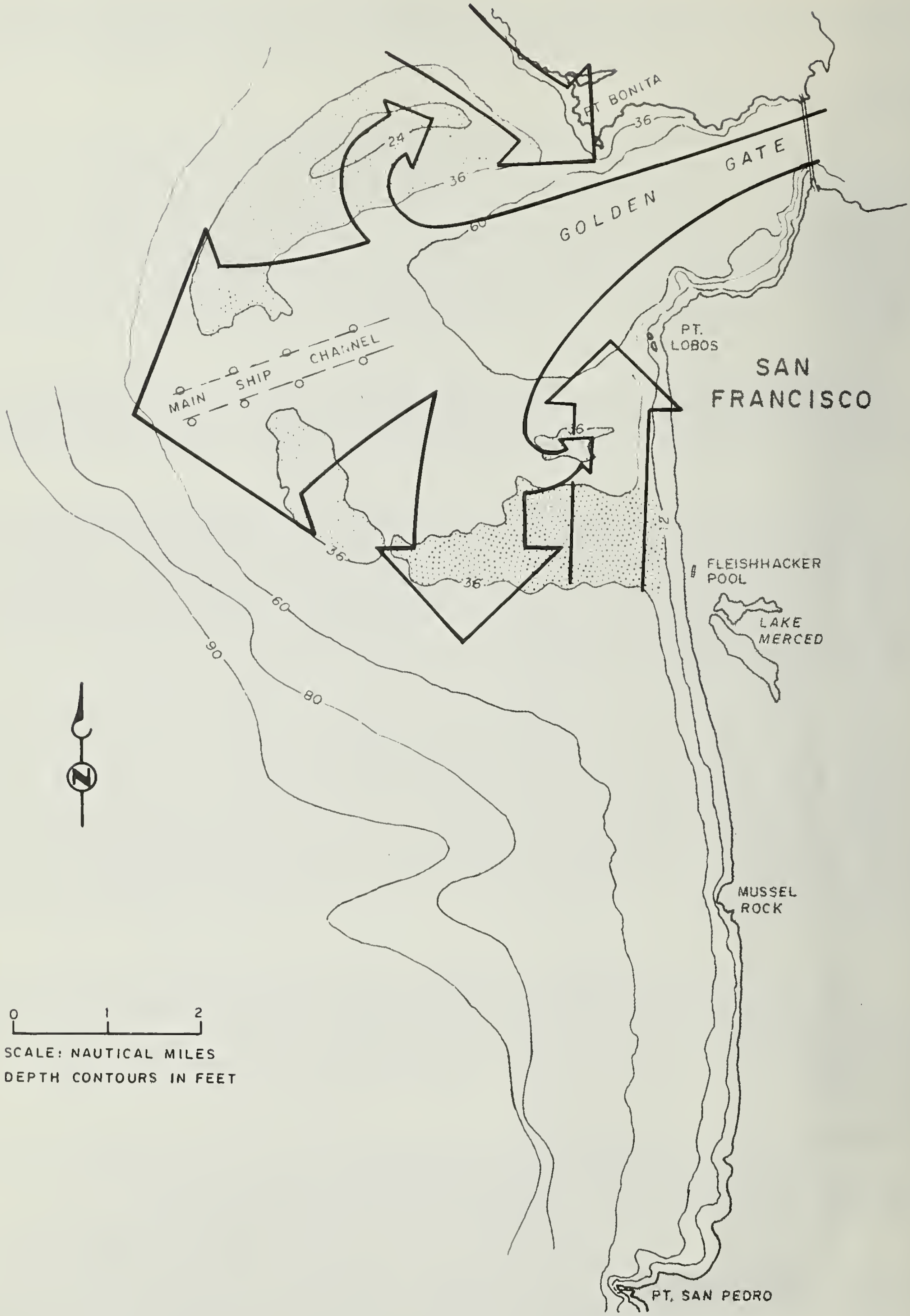


Fig. 3-3. Schematic Diagram of Surface Advection in Gulf of Farallones

hydraulic head, fresh water from the bay tends to flow out and stratify vertically over the more dense ocean water. Waters affected by this outflow consequently show large vertical gradients in both salinity and density. During the 1970 studies, salinity values at some stations within the Gulf of the Farallones are as low as 10 ppt (parts per thousand) in surface waters and as high as 30 to 32 ppt in bottom waters. Due to the nature of the observed two-layer flow pattern, the physical-chemical characteristics at any one location were highly dependent upon the tidal stage.

Dissolved oxygen profiles during the winter cruises showed a marked uniformity at all stations and depths. Readings usually fell within the range of 8 to 9 mg/l with minimum and maximum values of 7.8 and 9.2 mg/l, respectively.

Physical-chemical characteristics measured in the summer indicated several significant differences as compared to the winter measurements. The strong layering created by high freshwater outflow during the winter months had disappeared by June. The minimum surface salinity measured outside the Golden Gate in June was 30.8 ppt, compared with values as low as 10 ppt measured during February. However, there was still evidence of some reduction in surface salinity due to freshwater outflow, particularly on an ebbing tide. Stations south of the bar showed a marked thermocline at about a 40 ft depth, with temperatures below that level as much as 4 C colder than in the surface layers. The striking parallel between temperature and dissolved oxygen profiles indicated that the bottom layer was characteristic of deeper ocean water, which had been brought to the area by upwelling. Dissolved oxygen values in the upper 30 ft of the water column in the vicinity of Station Y were typical of surface waters of the ocean in this area and averaged about 8 mg/l. Below 50 ft, dissolved oxygen concentrations dropped off to an average of about 4 mg/l. Inside the bar at Station X and vicinity, dissolved oxygen values averaged about 6.5 mg/l throughout the entire depth.

The distance from the surface to the layer of upwelled deep ocean water can be expected to vary depending on the strength and duration of the winds which cause upwelling to occur. During the June cruise the depth was consistently about 40 ft, but at other times it may reach the surface or be absent altogether. The incidence of surface upwelling is lower south of the Golden Gate than to the north, however. This is indicated by records of surface temperatures for the area and by the incidence of fog, which is much greater north of the Golden Gate.

Water clarity during the summer cruise was greater south of the bar than inside the bar. Secchi disc readings inside the bar over three days of observation ranged from 5 to 11 ft with a median of about 8 ft. South of the bar, the range was from 6.5 to 21 ft, with a median of about 16 ft.

The investigations of the 1970 fall season were carried out to provide oceanographic data at specific points where it was anticipated that an outfall diffuser might be located. Accordingly Stations A and B (Fig. 3-1) were selected for investigation over a complete tidal cycle. Station A was located in 45 ft of water approximately 5,500 ft offshore of the southern edge of Golden Gate Park in an area where current velocities are slower than in the deeper portion of the main channel to the north. It also represents approximately the shallowest depth at which one might construct a satisfactory outfall diffuser for a relatively small flow. Station B was located in 90 ft of water six nautical miles from Point Lobos. This location is outside the bar to the west, and was selected for comparison with Station Y, outside the bar to the south, which had been investigated on the June cruise.

Water density measurements at Stations A and B were consistent with general trends in mass water movements developed from other information. Fronts of low density water, at times extending from the surface to the bottom, moved past Station A on an ebb tide with more dense water returning on a flood tide. At Station B, the water below a depth of 45 ft was near oceanic density at all times, with little evidence of tidal fluctuation. However, in the surface layer, there was clear evidence that a low density layer moves past the station with each strongly ebbing tide.

Fall dissolved oxygen measurements at Station A showed little variation with time and depth, indicating more complete mixing inside the bar. Maximum and minimum values were 8.3 and 6.3 mg/l, respectively. Dissolved oxygen at Station B showed variation with both time and depth. Surface dissolved oxygen was high during the daylight hours of October 10 due to photosynthetic activity by phytoplankton, but dropped sharply at about 16000 hours when an ebb tide moved a surface layer of lower salinity water past the station. Below 70 ft at Station B, dissolved oxygen was virtually constant at 5.4 to 5.8 mg/l.

Fall water clarity measurements at Stations A and B were generally greater than measured in the summer season, ranging from 12 to 17 ft at Station A and from 16 to 24.5 ft at Station B.

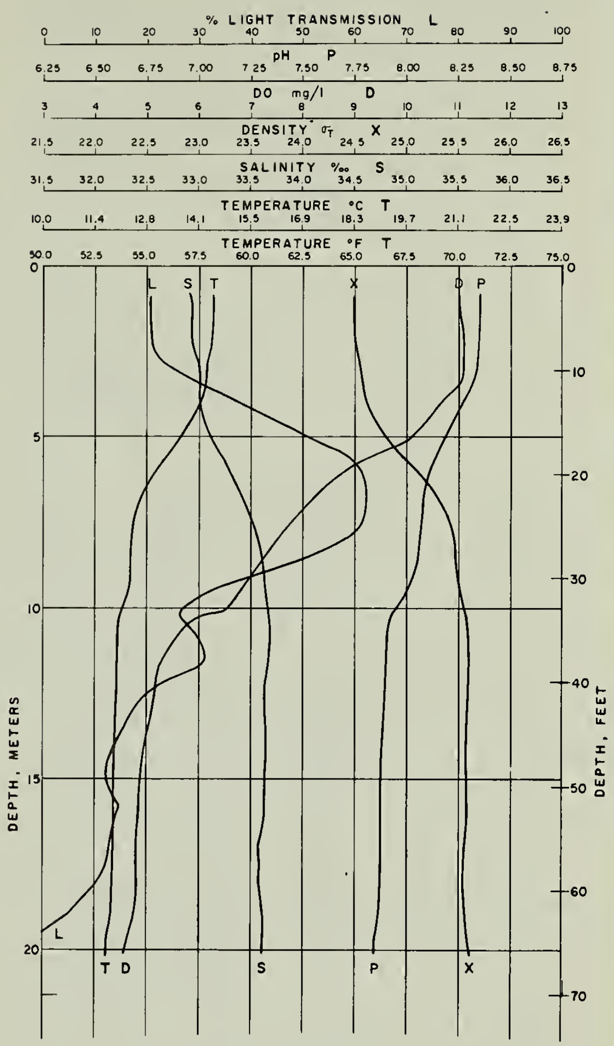
1973 Studies. Results of physical-chemical measurements made in the fall of 1973 at Stations 1 and 2 in the Gulf of the Farallones are contained in the appendix. Representative examples are presented in Fig. 3-4 and 3-5. The vertical profiles were used to develop graphs (Fig. 3-6 and 3-7) of the vertical distribution of each physical-chemical characteristic over a tidal cycle.

For purposes of convenience, density is expressed in terms of σ_t (sigma-t), which is defined as the difference between the density of salt water and of fresh-water at standard temperature, multiplied by 1000. Thus, a density of 1.0250 grams per cubic centimeters is essentially equal to a σ_t of 25.0.

The water density profiles shown in Fig. 3-4 and 3-5, as well as those appendixed, all exhibit an increase in density of the water from the surface to the bottom. The smallest measured density gradient, the condition most likely to result in the surfacing of a sewage field, occurred at Station 2 at 1400 on October 3. This profile, included in Fig. 3-5, shows an almost uniform rate of change from a density at the bottom and at 60 ft of 25.8 to a value of 24.2 at the surface. At that time, during a short flood tide, tidal currents at Station 2 were very slow. At Station 1, the minimum salinity gradient occurred at 0130, October 3, at the end of a long ebb current.

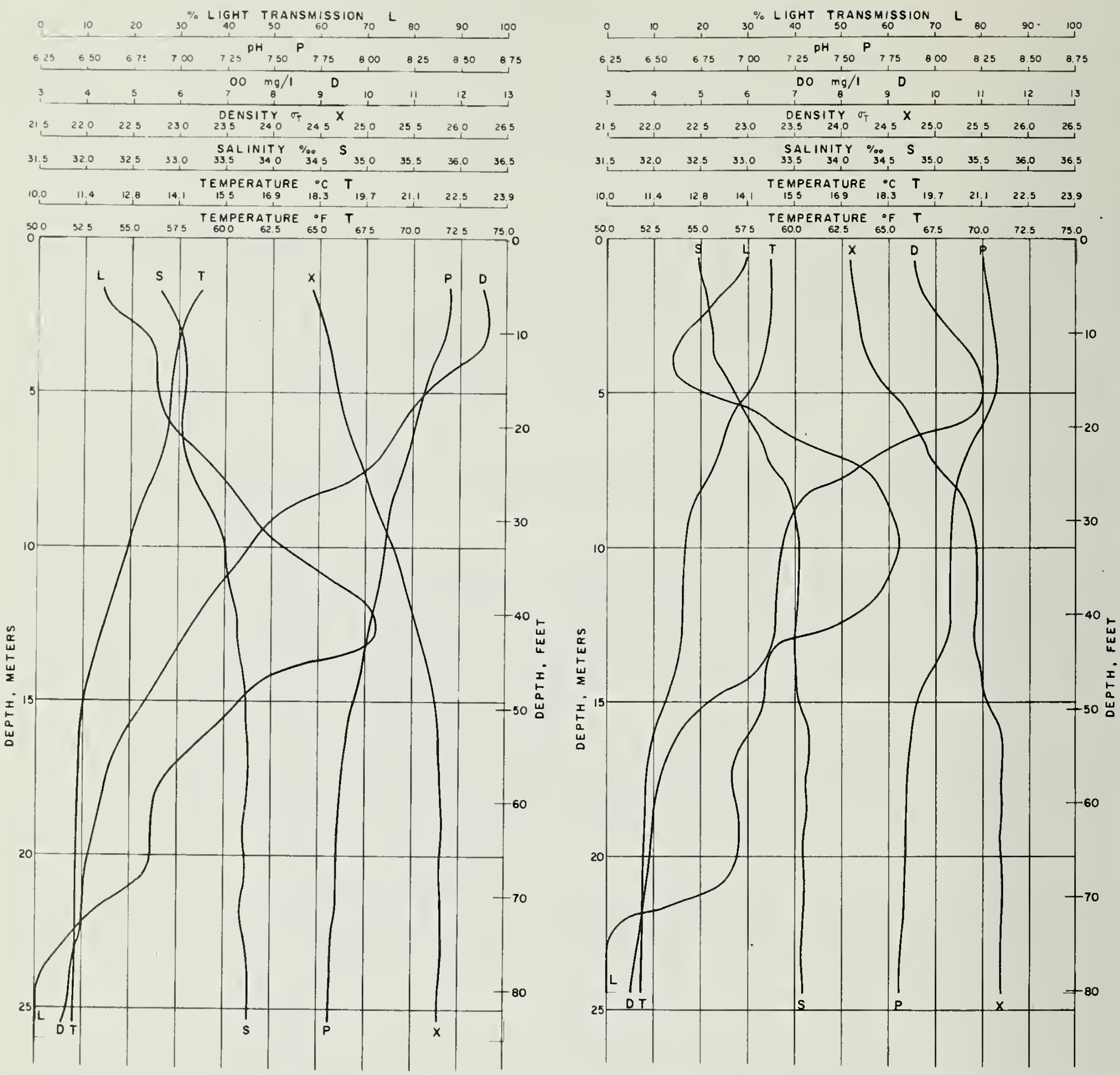
Changes in water density shown in other profiles usually occur rapidly within a vertical distance of 10 to 20 ft. Such steep density gradients are termed pycnoclines and often mark the interface of separate water masses and may be observed in changes of other physical-chemical parameters shown on the profiles. Changes in physical-chemical characteristics of waters at the pycnocline indicate that the upper layer primarily comprises ebb flow from the Golden Gate, whereas the lower layer is primarily the more saline ocean water. At times, both a major and a minor pycnocline are evident (Fig. 3-4 and 3-5). The minor pycnocline tends to occur deeper and may be the remnant of an earlier ebb tide. A similar phenomena was very evident in surface turbidity patterns of successive ebb tides observed in 1970 (Brown and Caldwell, 1971).

1400 PDT October 2, 1973



1830 PDT October 2, 1973

Fig. 3-4. Selected Profiles of Physical-Chemical Characteristics at Station 1



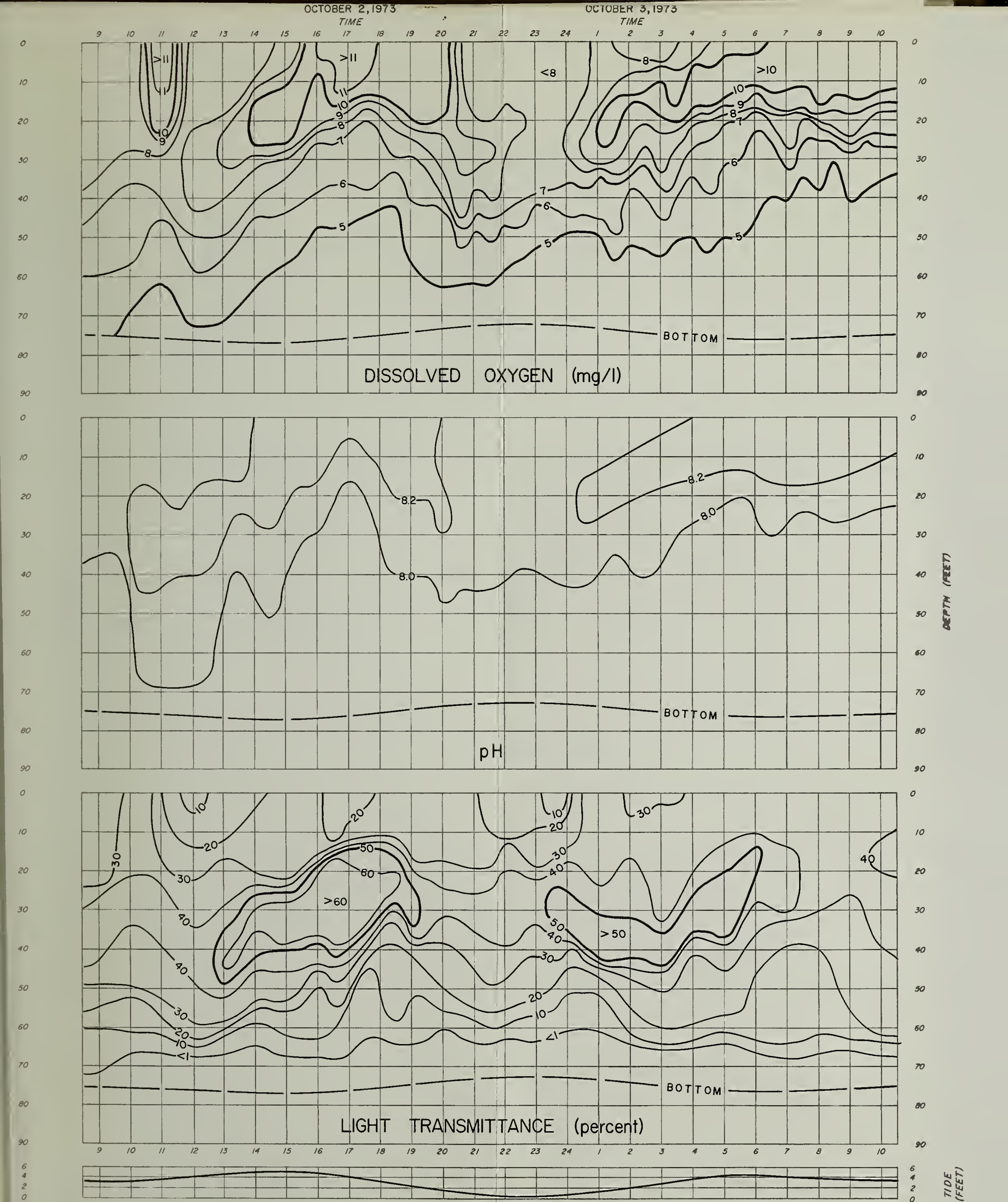
1400 PDT October 3, 1973

2000 PDT October 3, 1973

Fig. 3-5. Selected Profiles of Physical-Chemical Characteristics at Station 2


OCTOBER 2, 1973
TIME
OCTOBER 3, 1973
TIME
TEMPERATURE (F)
BOTTOM
59
58
57
56
55
54
53
SALINITY (ppt)
32.0
32.5
33.0
33.5
DENSITY (sigma-t)
24.0
24.5
25.0
25.5
DEPTH (FEET)
TIDE (FEET)

S



ATION 1

Fig. 3-6 Time Variations of Physical-Chemical Characteristics with Depth, Station 1

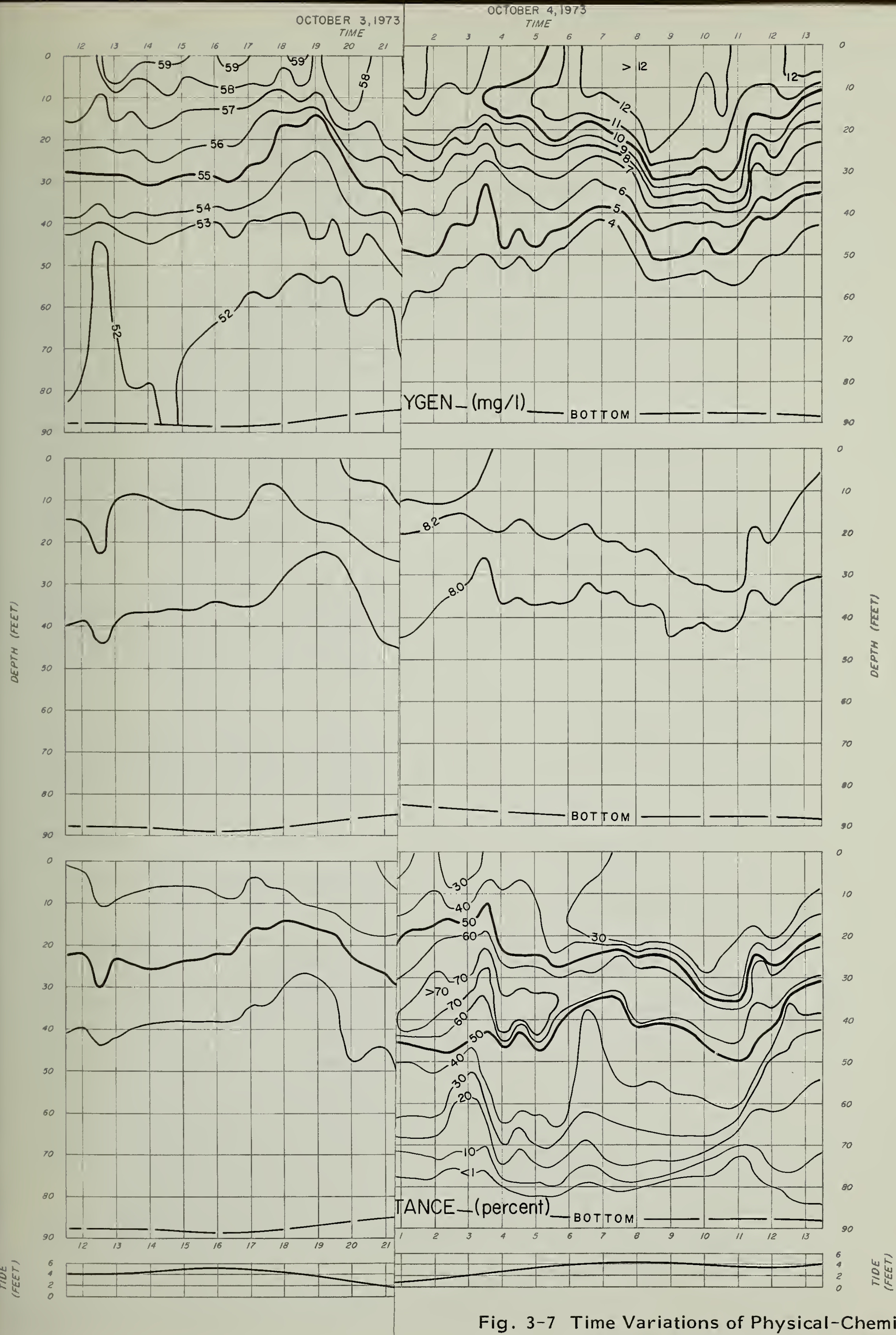
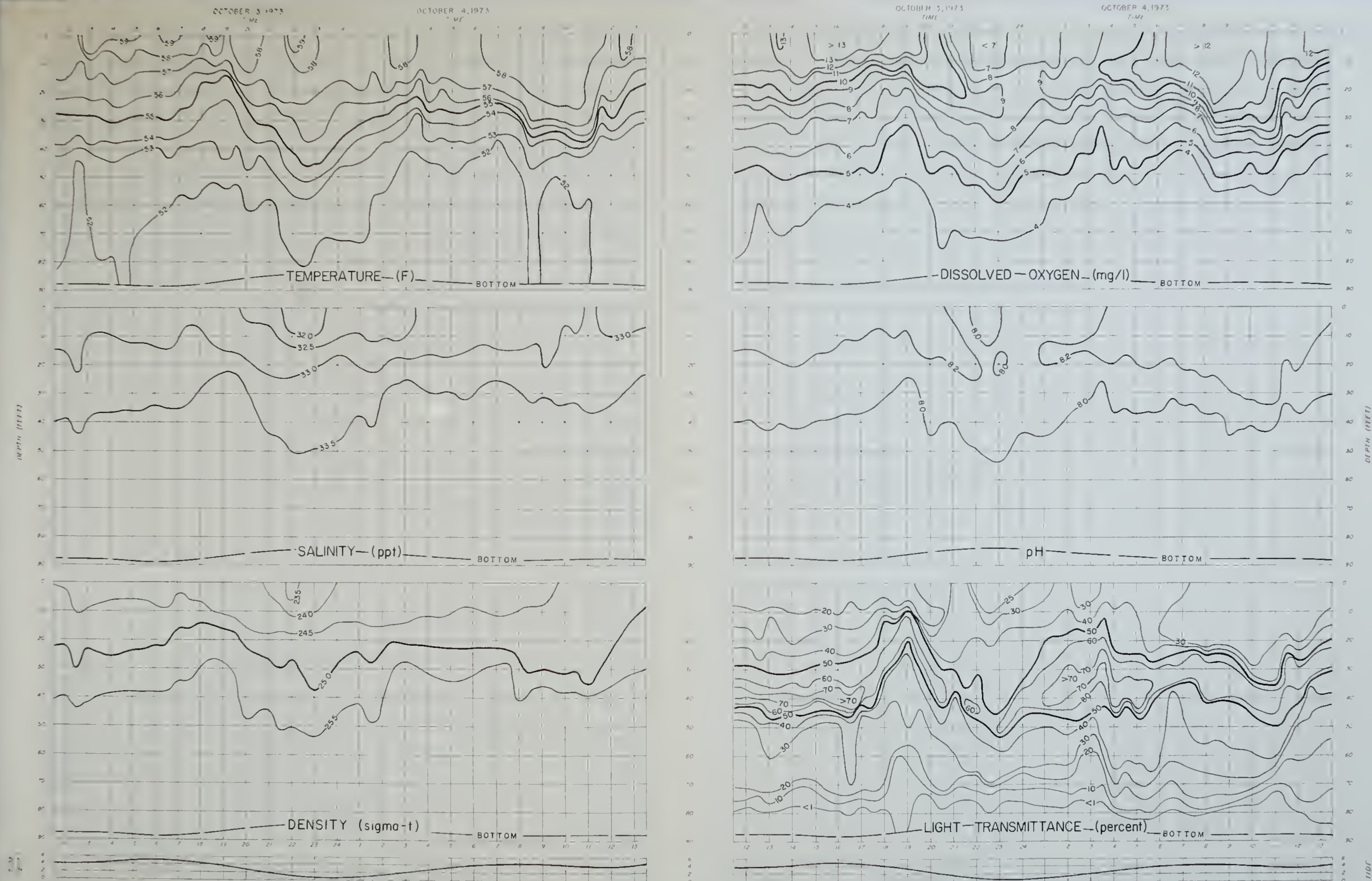


Fig. 3-7 Time Variations of Physical-Chemical Characteristics with Depth, Station 2



STATION 2

Fig. 3-7 Time Variations of Physical-Chemical Characteristics with Depth, Station 2

The effects of tidal ebb and flood currents on temperature, salinity, density dissolved oxygen, pH, and light transmittance are seen in Fig. 3-6 and 3-7. During ebb flow, the upper layer has a higher temperature and lower salinity and density, and is relatively thick. During the flood current, incoming colder, more dense water in the lower layer causes a thinner upper layer at a given location. The depth to the pycnocline ranged diurnally from 15 ft at both stations to 40 ft at Station 1 and 35 ft at Station 2.

Dissolved oxygen concentrations measured in the upper layer of the water column at Station 1 and 2 varied considerably during the tidal cycle, while the concentration in the lower layer, beneath the pycnocline, remained relatively constant (Fig. 3-6 and 3-7). Daytime supersaturation occurred in the upper layer and is strong evidence of photosynthetic activity of phytoplankton. Below the pycnocline, minimum dissolved oxygen concentrations were less than 5 mg/l at Station 1 and less than 4 mg/l at Station 2. Decline in dissolved oxygen from high surface values is caused by oxidation of organic matter and is typical of dissolved oxygen profiles in the ocean depths. Compared with the previous 1970 fall season dissolved oxygen data measured at Station B, the present data basically show the same day-night pattern of dissolved oxygen concentration variation. However, the upper layer concentrations at Stations 1 and 2 are greater and the lower layer concentrations are smaller than those measured at Station B.

The pH distributions shown in Fig. 3-6 and 3-7 are similar to the distribution pattern of dissolved oxygen concentration. Higher pH values are associated with high dissolved oxygen concentrations due to carbon dioxide uptake by plants during photosynthesis and substantiate the view that the supersaturated values of dissolved oxygen are produced by photosynthesis. The pH values were slightly alkaline, typical of normal oceanic conditions.

As shown in Fig. 3-6 and 3-7, the lowest turbidity, or greatest water clarity, was observed immediately below the pycnocline. This condition was most pronounced during each of the flood cycles when ocean water dominates the study area. During ebb periods depth of the more turbid upper layer increased due to outflow from San Francisco Bay, which has greater turbidity.

<u>Currents</u>

Seasonal changes in the mass movement of surface waters beyond the Golden Gate are also reflected in the current patterns at various depths.

<u>1970 Studies</u>. The occurrence of highly stratified waters in the Gulf of the Farallones in winter results in different currents in the upper, less dense waters than in the lower, more dense waters. The general characteristics of currents near the mouth of the Golden Gate during the winter season of massive freshwater outflow is consistent with salinity and density characteristics discussed earlier. A thin layer of low salinity and density surface water moves rapidly and almost continuously westward and southward. Surface layer currents were highest near the mouth of the Golden Gate where speeds were measured up to 4.5 K (Knots); the depth of this surface layer of water was less than 15 ft. A fairly balanced pattern of ebb and flood currents was measured at this depth, and flood currents predominated near the bottom. Current speeds measured at 15 ft and near the bottom were significantly less than those measured at the surface.

At Station 98 on the south edge of the bar, current speeds at 15 ft depth ranged from 0.4 to 0.9 K. The maximum ebb and flood velocities were about equal, but net flow was to the south.

Measured winter current patterns west of the Golden Gate in the Gulf of the Farallones thus described a typical circulation pattern for a positive estuary, with a predominant flow of low salinity water outward on the surface and a predominant flow of high salinity ocean water inward near the bottom. The bottom flow was further confirmed by a 1970 U.S. Geological Survey report (Conomos, 1970) on the movement of seabed drifters in San Francisco Bay and the Gulf of the Farallones. That report described the movement of seabed drifters into San Francisco Bay from as far as 25 kilometers (15 miles) west of the Golden Gate, which is about the same distance that tidal outflow was clearly visible in these studies. The seabed drifter studies described in the 1970 USGS report were conducted during March, 1969, and therefore represent the same oceanographic conditions measured in connection with the winter study in February 1970.

Current measurements in the summer (July and August, 1953 and June, 1970) differed significantly from those measured in winter. Although there was still a recognizable difference between surface and subsurface currents, the large differences which were characteristic of the winter period had essentially disappeared. All current measurements showed a predominant influence of tidal ebb and flow from San Francisco Bay. As was expected, the stations farthest from the Golden Gate exhibited the weakest currents and least tidal influence. Advective flow diagrams demonstrated a predominant southeasterly flow through Bonita Channel, supplying a major portion of the volume for the flooding tidal prism.

Stations 64, 65 and 66, at the mouth of the Golden Gate, predictably showed the highest current values of any stations during the summer. Average values were in excess of 1 K and maximum values faster than 3 K. U.S. Coast and Geodetic Survey measurements at 8 ft depth were made in 1953 at Station 73 situated on the bar just north of Station 98 (Fig. 3-1). Net advective flow was to the southwest in one 24-hr period and strongly so in another.

Current measurements at Station Y and vicinity, situated south of the bar and 3.5 miles offshore, were taken during a period of minimum tidal current. Generally, currents were directed to the northeast towards the bay on flood and to the southwest on ebb tide.

Fall measurements of currents in the Gulf of the Farallones in 1970 were made at Stations A and B. Surface advective flow measured at Station A showed an approximate balance between flood to the northeast and ebb to the southwest, and rather surprisingly showed a pronounced shoreward displacement. This was the first time that a shoreward current vector in this area had been recorded, and its presence at this time of year was confirmed by the shoreward movement of a dye patch dropped near Station A on October 5, 1970. It is likely that the currents within about 2,000 ft of the beach were parallel to the shore. This had been suggested by previous surveys but could not be confirmed in the October measurements. Advective flow diagrams for a 33 ft depth at Station A showed a definite flood predominance.

Currents at Station B in the fall were small in magnitude compared to currents inside the bar. The average velocity was about 0.6 K at the surface and 0.4 K at depths below 30 ft. Currents at an 80 ft depth were even slower, with many measurements below the minimum measurable value of 0.2 K. The conclusion from these current measurements, which is supported by information on salinity and dissolved oxygen, was that very little water movement takes place near the bottom at Station B.

1973 Studies. Current measurements obtained during the 1973 fall season investigation are tabulated in appendix. They also are discussed below in several ways to indicate interesting aspects of the current regime observed at Stations 1 and 2.

Computed advective flows past each station for three zones of the water column are presented in Fig. 3-8. The upper zone is defined as that depth ranging from 3 to 10 ft beneath the water surface; the mid-zone is 20 to 30 ft. The lower zone ranges from 50 to 60 ft at Station 1 and from 60 to 70 ft at Station 2. Currents presented for each zone are the vector averages of currents measured at two or more depths within the zone. The mid-zone is at a depth where the pycnocline occurs most often and thus represents a transition zone. Net measured advective flow at Station 1 was directed away from the coast in the upper zone, slightly offshore in the mid-zone and slightly to the east of north in the lower zone. Net measured advective flow at Station 2 was directed away from the coast in all three zones. A comparision of these flows with advective flow diagrams determined for surface, mid-depth (33 ft) and near-bottom (66 ft) conditions at Station B in the fall of 1970 showed that, although measured speeds were smaller at both Stations 1 and 2, directions of net advective flow in all three zones at Station 1 were essentially the same as found earlier at Station B. At Station 2, only the upper zone currents were similar to those at Station B.

Because the depth range of the mid-zone is not consistently above, below, or within the major pycnocline zone, a question arose as to the significance of the advection diagrams for this zone (Fig. 3-8). Utilizing individual profiles, the current vectors for Station 1 situated within or closest to the pycnocline zone were summed and compared to the vector summation computed for the mid-zone. The direction (bearing) values were found to be almost identical and the sum of velocities was only slightly greater for the pycnocline zone than for the mid-zone. Hence the mid-zone advection diagrams reasonably portray the net movement within the pycnocline.

The presentation of current data in Fig. 3-9 and 3-10 shows magnitude and direction of the measured surface and bottom currents at Stations 1 and 2 as a function of time. The length of each vector in the diagrams is proportional to the measured current velocity. Again, the vector in the specific layer is the average of currents measured at two or more depths within the layer at approximately the same time. Since the tidal circulation patterns at Stations 1 and 2 cause generally northerly currents to flow during flood tides and southerly flow regimes to exist during ebb tides, all of the current directions and velocities have also been averaged for the basic northerly and southerly current directions. The overall average current flow was also computed. These figures show a net advective flow in the upper layer at both Stations 1 and 2 that is directed away from the coast. Net advective flow in the lower layer was typically smaller than in the upper layer, and although slightly offshore at Station 2, was toward the entrance to the bay at Station 1.

Relationships between surface layer current patterns and tide and wind conditions may be evaluated using Fig. 3-11 and 3-12. As expected, these figures indicate that the upper layer currents at Stations 1 and 2 are strongly influenced by tide changes, with peak current speeds somewhat lagging conditions where maximum time rate of change of tide height is occurring.

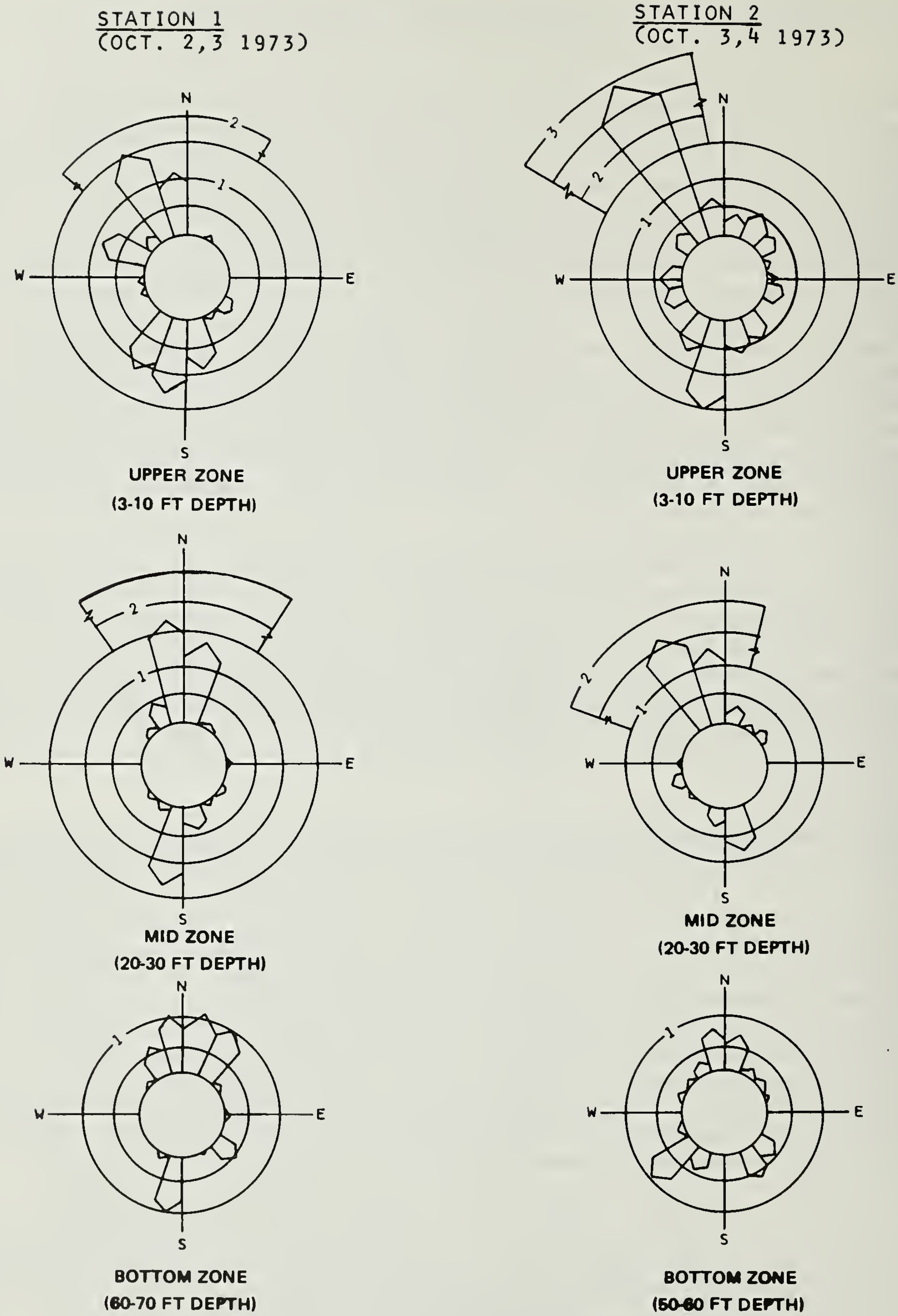


Fig. 3-8. Advective Flow in Knots by 20 deg Sectors for One Tidal Cycle (25 hr)

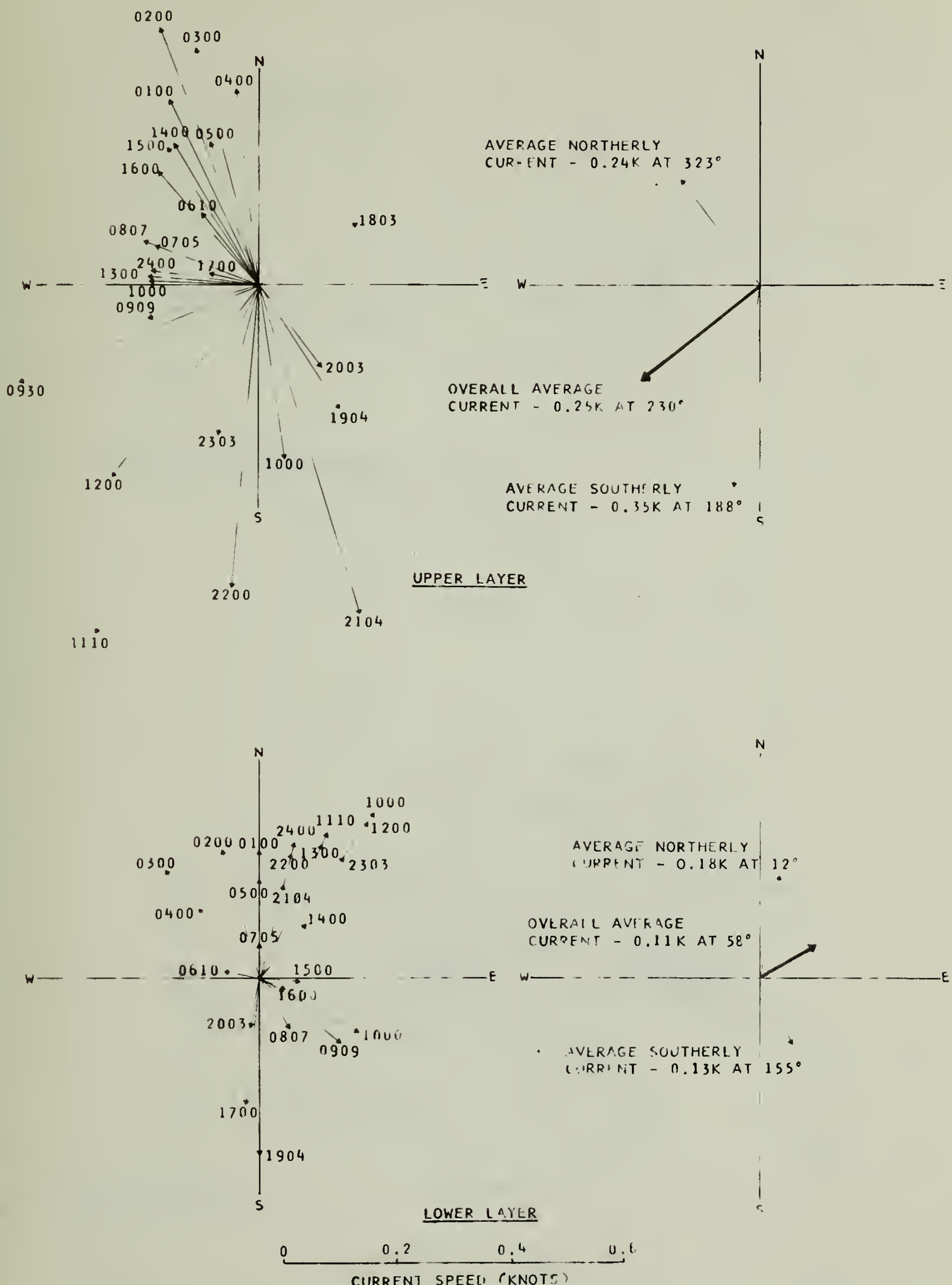


Fig. 3-9. Currents at Station 1 for One Tidal Cycle (25 Hr)

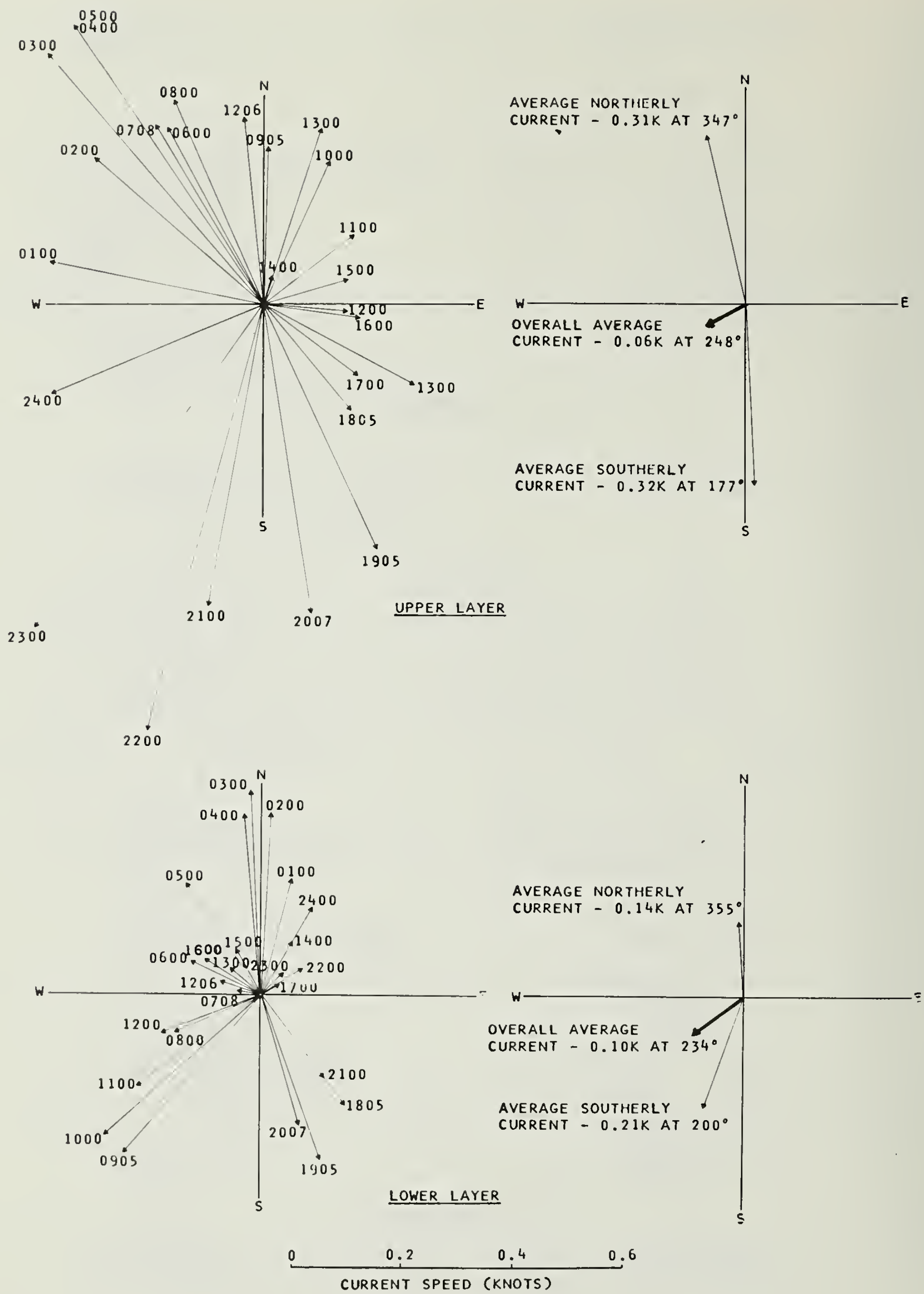


Fig. 3-10. Currents at Station 2 for One Tidal Cycle (25 Hr)

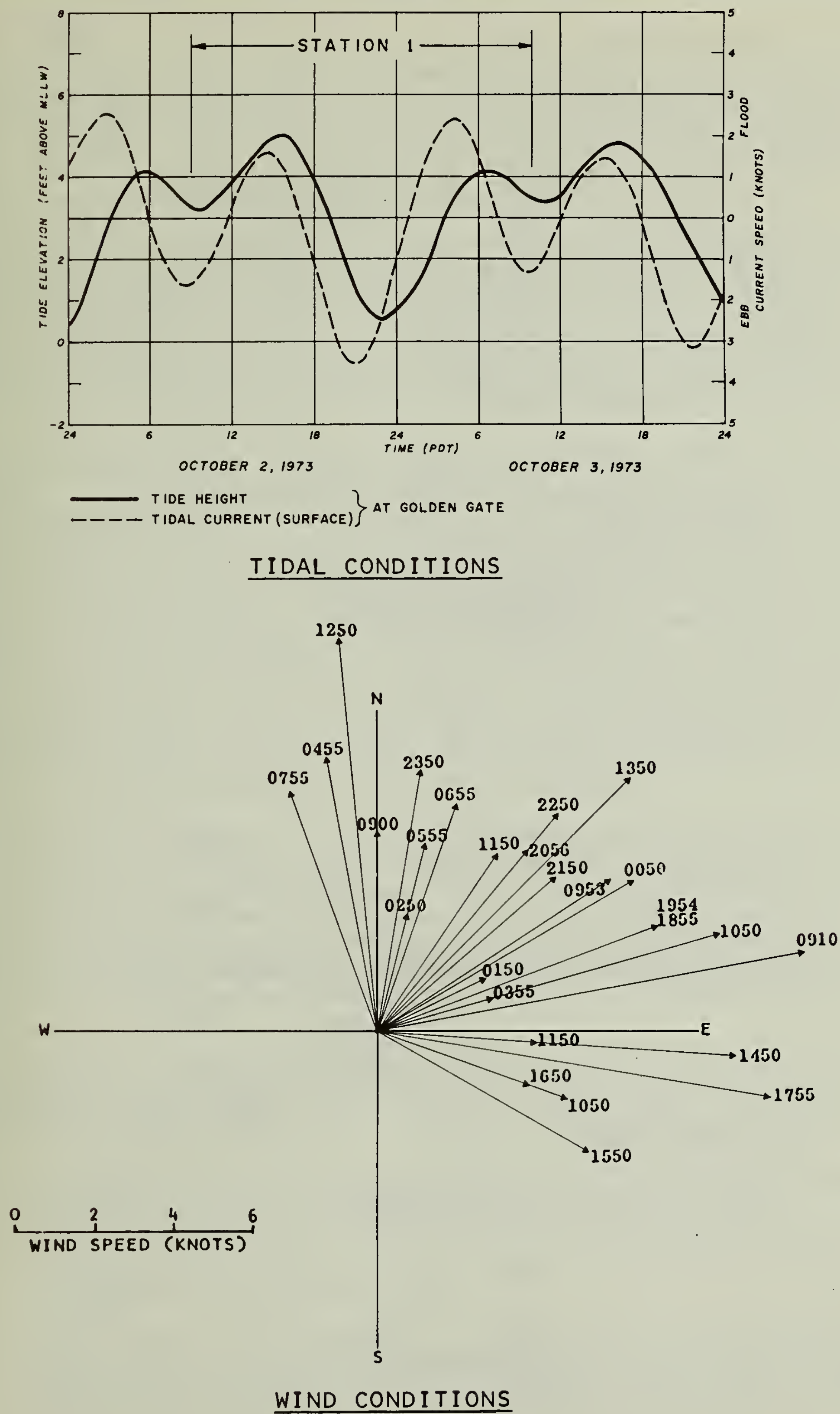


Fig. 3-11. Tide and Wind Conditions at Station 1, Oct. 2, 3 1973

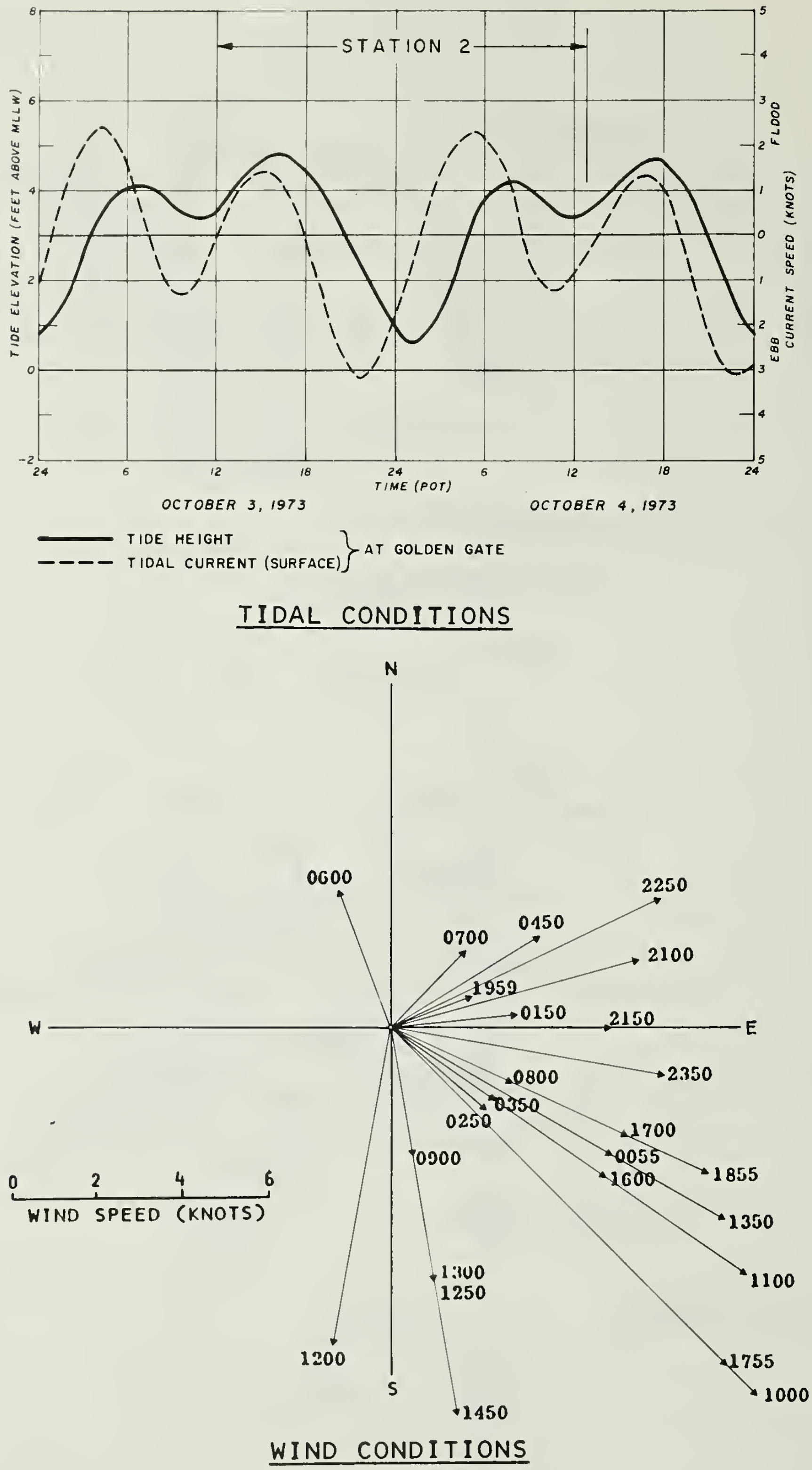


Fig. 3-12. Tide and Wind Conditions at Station 2, Oct. 3, 4 1973

Surface Drift

The movement of that portion of the water column referred to as the surface water film is highly influenced by wind and may be quite different from the movement of the water column beneath it. Since floatable particulates resulting from marine effluent disposal may collect in the surface water film, it is important to define the surface drift characteristics of the film.

1970 Studies. The first surface drift measurements conducted in this study were carried out during the period from June 16 to June 23, 1970. Three drops of 1,500 cardboard milk bottle caps each were made at both Station X and Y in the Gulf of the Farallones and at Station Z in the central bay between Blossom Rock and Alcatraz Island. Drops were made as close to the time of tidal nodes as other duties in the oceanographic work program would permit, and each batch of caps was spread over a distance of about 600 feet to simulate initial dispersion of an effluent field.

Two interesting facts to emerge from the June 1970 surface drift were the following: (1) of a total of 13,500 caps dropped at all three stations, not a single cap was recovered inside the Golden Gate, and (2) of the 4,500 caps dropped at Station Z in the central bay, not a single cap was recovered at any location. A lower percentage recovery would normally be expected within the bay because the ratio of shoreline searched to total shoreline was lower than along the ocean beaches. However, the areas selected for investigation within the bay were those most sensitive esthetically to the accumulation of floatable materials, and the fact that not a single cap was recovered at any point is significant. The failure to recover any caps from those dropped in the central bay is presumed to be evidence that the caps were carried so far seaward by the ebbing tide that they were either entrained in the major oceanic current system or simply could not be moved ashore by wind action in the week that elapsed before the final search was made.

Results of the surface drift measurements for Stations X and Y were consistent with information developed on mass water movement. Caps dropped at Station X were more likely to be swept along in the strong westward-flowing tidal ebb through the Golden Gate and dispersed in the oceanic current system. Caps recovered from Station Y, the southern station, were confined to the coastline south of the Golden Gate. The heaviest concentration was recovered from the San Mateo County coast in the vicinity of Thornton Beach State Park, which lies directly shoreward from Station Y.

Surface drift studies during October 1970 were conducted in the same manner as described for June. The most interesting aspects of the October studies are summarized as follows:

1. Caps were recovered along the ocean beaches from Point San Pedro to the Bolinas Peninsula, consistent with the June observations.

2. No caps from the ocean releases were recovered inside the bay, also consistent with June observations.

3. Only 16 caps from the central bay releases were recovered inside the Golden Gate, and 14 of these were recovered from the Marin Headlands area near Horseshoe Bay. This observation is also in basic conformance with the June data, when no caps were recovered from the bay.

4. Unlike the June results, when no caps were found from any of the bay releases, caps from the October releases inside the bay were found in significant quantities both north and south of the Golden Gate. This may result from the fact that in October the seaward movement of the ebbing water mass was somewhat less than in June.

A previous surface drift study had been conducted in the Gulf of the Farallones by Brown and Caldwell in 1962 in connection with design of a submarine outfall for North San Mateo County Sanitation District. Bottle caps were released at eight locations from 700 to 2,300 ft offshore immediately west of Lake Merced on July 20 and 26. The observed shoreward velocity ranged from 11 to 37 fpm, and substantially all of the caps released arrived at the beach in less than three hours. The caps were distributed along the beach for a distance of 7,000 ft north of the release point and 3,500 ft south of the release point.

The second independent study of surface drift was conducted in the Bolinas area in August, 1966 in connection with the Marin County Sewerage Study (Brown and Caldwell, 1967). Two releases of 500 caps each were made 2000 ft offshore. Of the caps dropped offshore of Rocky Point, 83 percent were recovered from the adjacent beaches, most within a period of four hours. Of the 500 caps dropped 2000 ft offshore of Bolinas Mesa, where a prevailing northerly current had been defined running parallel to the coastline, 30 percent were recovered. The average shoreward velocity in the former case was about 10 fpm. In the latter case the shoreward velocity was not well documented, but was less than 7 fpm.

1971 Oil Spill. The massive oil spill from colliding tankers on January 18, 1971 occurred under the Golden Gate Bridge and continued after the ships were towed to the vicinity of Angel Island. Within San Francisco Bay the oil contamination of the shoreline was limited to areas adjacent to and seaward of the point of release. Severe contamination occurred to ocean beaches from Duxbury Point on the north to Point San Pedro on the south. The distribution thus confirmed the findings of the bottlecap drift studies.

1973 Studies. Surface water movements in the vicinity of Station 2 were observed on October 1973 by following the movement of Rhodamine B dye patches. Two separate releases of dye, approximately one and one-quarter hours apart, were made directly to the water surface at Station 2 during a short flooding tide in the mid-afternoon of October 3. The results of aerial and boat tracking of these patches are presented in Fig. 3-13. At the start of the dye tracer releases, the surface tidal current was flooding toward the north, and the wind was blowing toward the southeast. During the three-hour period that the two dye patches were tracked, the current in the upper layer slowly rotated clockwise and began to flow southeast at the end of the tracking period. Meanwhile, the wind remained generally toward the southeast throughout the period. Shoreward movement during the period was about 1.4 nautical miles for the first dye patch and 0.5 nautical miles for the second. Although tracking of the dye releases was limited to a short period of time due to fog, these dye patch data are consistent with current and wind data.

Dispersion Studies

Data obtained from the study of the spreading of dye patches during the winter, summer, and fall cruises are presented in detail in Volume I (Brown and Caldwell, 1971) as is the analysis of the data. In brief, dispersion coefficients for the study areas within the Gulf of the Farallones and within San Francisco Bay were determined to correlate strongly with scale expressed as the length or width,

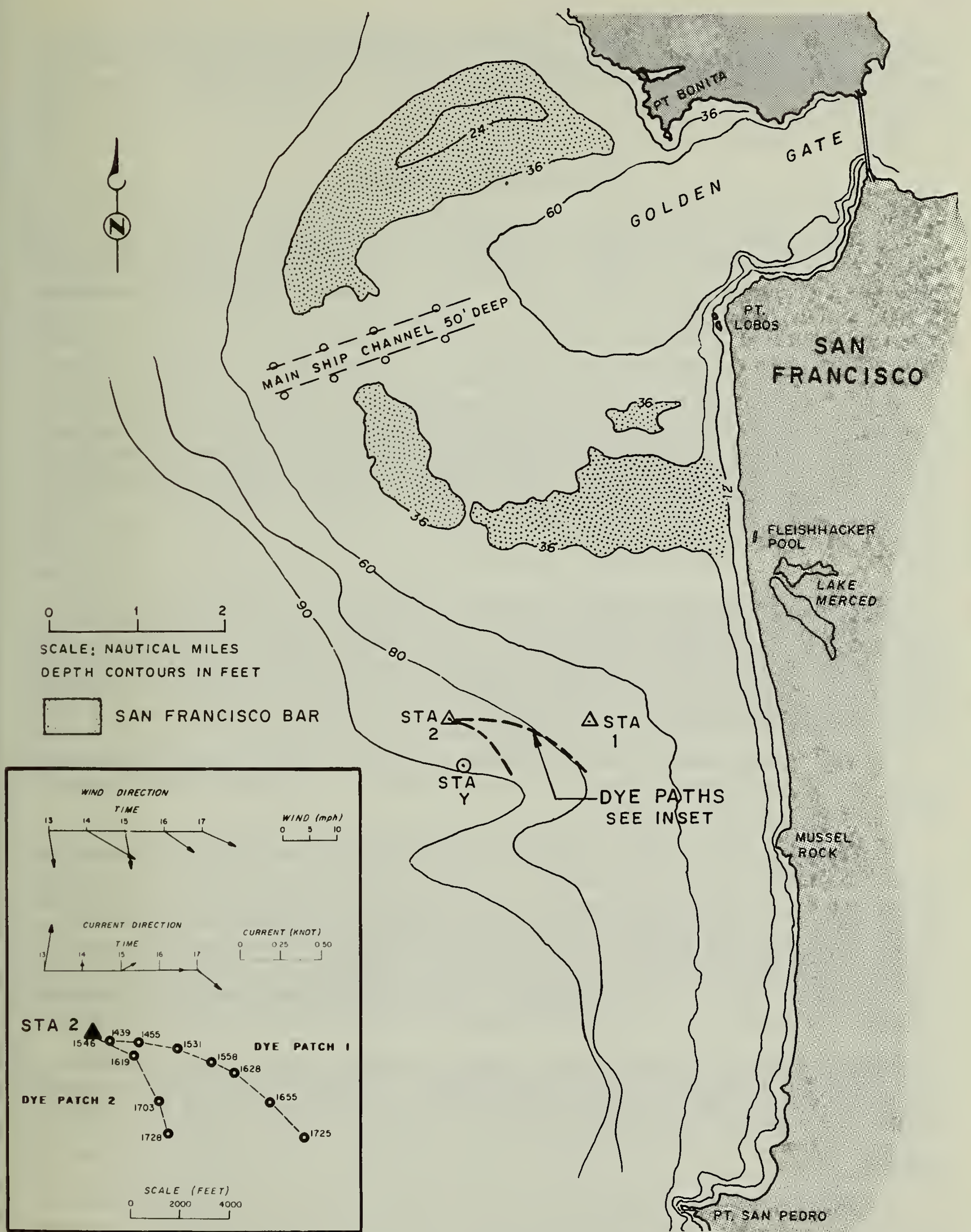


Fig. 3-13. Dye Patch Movement

L, of the patch but not to other conditions such as current, wind, wave height or season. The coefficients, expressed as $k = 20L^{4/3}$ for the gulf and $k = 33L^{4/3}$ for the bay, are several times higher than others have reported for open ocean conditions.

OCEANOGRAPHIC SUMMARY

Oceanographic data collected in 1970 and 1973 provide the basis for site selection and preliminary design of submarine outfalls located offshore from Lake Merced, south of the Golden Gate. Use of the data in developing the outfall design will be discussed in Chapter 7. The present discussion summarizes the oceanographic characteristics of the Gulf of the Farallones during each of the three major seasons, with emphasis on the area designated for the outfall location.

Within the Gulf of the Farallones, the principal influence on oceanographic characteristics are the tidal flows to and from San Francisco Bay. The size of the area most strongly influenced by tidal flows varies with the season of the year, being greatest during the winter season of high freshwater outflow and smallest during the fall season of low freshwater outflow.

Winter

Studies of mass water movement through the Golden Gate indicate that during periods of high freshwater outflow, the ebbing surface layer will move westward and south along the coast well past the Lake Merced area. Most of the water leaving the bay on the ebb tide is replaced during flood tide by ocean water which comes principally from the north through Bonita Channel, from the south around Point Lobos, and along the bottom under the ebbing surface layer.

Current measurements made at Station 98, on the southern edge of the bar about 3.5 nautical miles offshore indicate that at the 15 ft depth a fairly balanced pattern of ebb and flood prevails.

Variations in physical-chemical characteristics of the water with depth strongly reflect the layering from the outflow of fresh water on the surface. Salinity and space density in the upper layer are low, increasing with depth to values typical of sea water. As the distance from the Golden Gate increases to the south, mixing of the fresh water with ocean water gradually reduces the marked salinity and density differences found at the gate. Often, upper layers of fresh water from two successive ebbs can be discerned. The strong stratification is not reflected in dissolved oxygen concentrations, which are close to saturation at all depths.

Surface drift studies were not conducted during winter, but from prevailing wind patterns, the 1971 oil spill, and studies conducted at other times of year, it can be expected that floatable material will tend to move toward the shore.

Summer

During the summer upwelling season, water flowing from the bay on the ebb tide moves westward and south past Lake Merced, as during the winter months, but because of reduced fresh water outflow, total displacement is less.

The marked vertical stratification in the area caused by high fresh water outflows is missing. Vertical stratification does occur but is caused both by outflow at a reduced level and by the movement into the area of upwelled ocean water which is cold, dense, and low in dissolved oxygen. During the data gathering work in June 1970, the depth from the water surface to the layer of cold ocean water was about 40 ft; the upwelled water may reach the surface at times.

Surface drift measurements utilizing cardboard milk bottle caps dropped at Station Y indicated that floatables discharged in this area would move toward the shore south of the Golden Gate. The heavist concentration of bottle caps was recovered directly shoreward in the vicinity of Thornton Beach State Park on the San Mateo County coast.

Fall

By late August or September, upwelling has usually subsided, and the period from this time to November is sometimes known as the Oceanic period. This time is considered to be the most critical for marine discharge of wastewater effluent. In addition to providing the least favorable characteristics in terms of vertical density gradients and freshwater outflow, water clarity is greatest and climatic conditions are most favorable to recreational use of the ocean and beaches; thus, any visible effects of an effluent field are most likely to result in objections by the public. Because of reduced fresh water outflow, displacement of the water mass flowing from the bay on the ebb tide is least during the fall.

Aerial observations in September and October 1970 show that the mass surface water movement on minor ebbing tides is directed southwestward toward and beyond the location of Stations Y, 1, and 2. This was confirmed by the physical-chemical measurements in the water column at Stations 1 and 2 in 1973. Except for brief periods at change in tide a definite two-layer structure of the water column was evident and the thickness of the upper warmer, less saline, and more turbid layer was greatest during ebb flow. The depth of the upper layer ranged from 15 ft on flood flow to 45 ft on ebb flow.

Dissolved oxygen was highest in the surface layer and exceeded atmospheric saturation value during flood flow in the daytime. Below the pycnocline the dissolved oxygen concentration declined to values in the 4 to 5 mg/l range.

Current data taken in 1973 at Stations 1 and 2 demonstrated the pattern of currents in this area. Advective flow diagrams and current diagrams show that motion is generally in a north-south direction with a net movement offshore at all depths at Station 2 and at top and mid-depth at Station 1. Net movement near the bottom at Station 1 was toward the Golden Gate.

Surface drift studies in 1970 showed that prevailing winds carried the surface film almost directly shoreward. Observation of a dye patch for a few hours in 1973 likewise showed the effect of wind on the surface water. Results of dispersion studies in October 1970 were similar to those for the other seasons. Calculated dispersion coefficients for the study area in the gulf and in the bay were found to be several times greater than has been reported for open ocean conditions.

CHAPTER 4

BENTHIC MARINE RESOURCES AT THE PROPOSED OCEAN DISPOSAL SITE

Biological field investigations were conducted to obtain general information on the species composition of the benthic fishes and macroinvertebrate fauna inhabiting the vicinity of the proposed ocean disposal site in the Gulf of the Farallones. Since there was little or no published information available at the inception of this study, the objectives of the sampling program were general in scope. There was not sufficient budget nor time to provide the type of specific sampling necessary for a rigorous quantitative description of the benthic infauna, bottom fishes or macroinvertebrate fauna. Thus, for example, there was no extensive period devoted to selection of the type of benthic sampler to be used nor were various size nets tested for trawling. Surveys were made from July 1973 to April 1974 and consisted of grab sampling for analyses of sediments and benthic infauna, bottom trawling to sample the fish and macroinvertebrate fauna, and trapping surveys to provide supplementary data on adult Dungeness crabs.

Previous ecological investigations by Brown and Caldwell (1971, 1973) included surveys of the intertidal, benthic, and planktonic biota at potential sites for wastewater disposal in the vicinity of the San Francisco Bar, which surrounds the entrance to the Golden Gate. Based on oceanographic data also collected by Brown and Caldwell (1971) in the area, the subsequent selection of potential ocean sites for disposal of wastewater narrowed to an area located two miles south of the San Francisco Bar and between two and four miles offshore. For this reason the California Department of Fish and Game (DFG) and the Regional Water Quality Control Board (RWQCB) recommended that additional studies be undertaken south of the bar to provide biological information about the proposed outfall site. The staff of the DFG Marine Resources Laboratory in Menlo Park was consulted on the plan of these studies and a DFG staff member was present during most of the surveys that were undertaken.

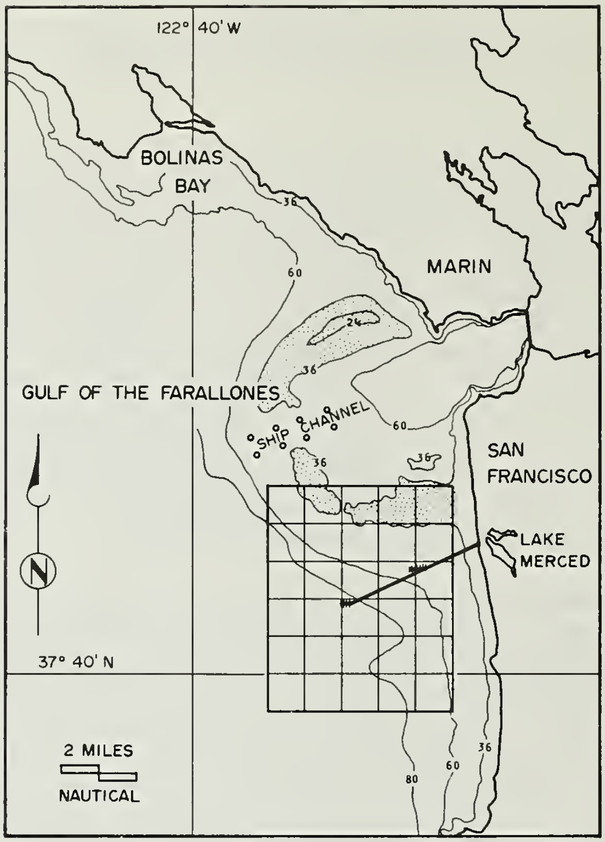
MATERIALS AND METHODS

The materials and methods used in the surveys are described below as they relate to the sampling stations, survey dates, sampling equipment and procedures, and sample processing procedures.

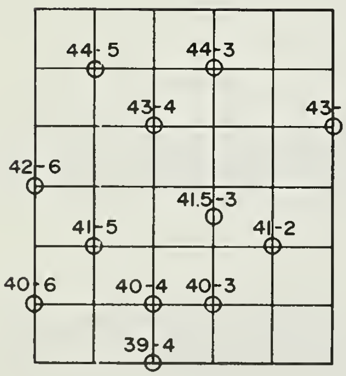
Sampling Stations

The number and location of sampling stations were selected after consultation with the staff of the California Department of Fish and Game at Menlo Park. The locations of stations were selected to correspond to depth contours and were also distributed with respect to the sampling grid (Fig. 4-1).

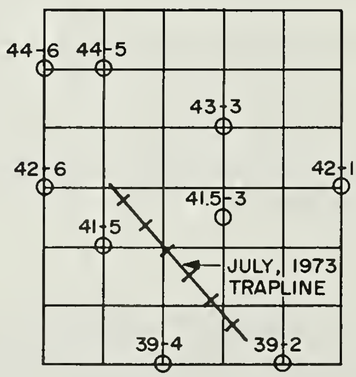
The stations are designated by the latitudinal and longitudinal lines. The latitudinal lines refer to the minutes north of 37 degrees north latitude, and the longitudinal lines are approximate distances from shore in nautical miles. Station 41.5-3, for example, is approximately 37° 41' 30" N latitude, three miles from shore. The positions of the sampling stations were fixed in the field using a Loran navigational system and radar.



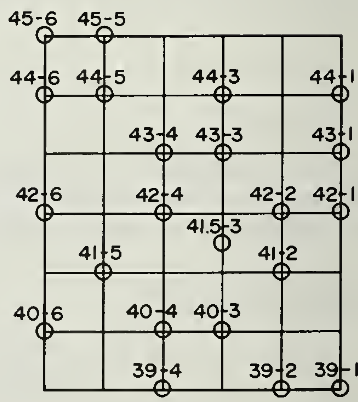
Station Grid and Proposed Alignment of Outfall



Bottom Trawl Stations



Crab Trap Stations



Sediment Sampling Stations

Fig. 4-1. Sampling Stations for Biological and Chemical Analyses, Gulf of the Farallones, 1973-1974

Dredge samples for sediment analyses and benthic infaunal organisms were collected at all 22 stations; bottom trawls were made at 12 of the stations; and crab trapping was done at nine of the stations (Table 4-1).

Table 4-1. Sampling Station for Bottom Trawl, Crab Trap and Sediment Grab Surveys, Gulf of the Farallones, 1973-1974

Station	North latitude	West longitude	Approximate depth, feet	Sampling method[a]
39-1	37° 39.0'	122° 31.2'	59	BG
39-2	37° 39.0'	122° 32.4'	79	BG, CT
39-4	37° 39.0'	122° 34.8'	85	BT, BG, CT
40-3	37° 40.0'	122° 33.6'	79	BT, BG
40-4	37° 40.0'	122° 34.8'	89	BT, BG
40-6	37° 40.0'	122° 37.2'	95	BT, BG
41-2	37° 41.0'	122° 32.4'	69	BT, BG
41-5	37° 41.0'	122° 36.0'	89	BT, BG, CT
41.5-3	37° 41.5'	122° 33.6'	79	BT, BG, CT
42-1	37° 42.0'	122° 31.2'	59	BG, CT
42-2	37° 42.0'	122° 32.4'	59	BG
42-4	37° 42.0'	122° 34.8'	79	BG
42-6	37° 42.0'	122° 37.2'	89	BT, BG, CT
43-1	37° 43.0'	122° 31.2'	39	BT, BG
43-3	37° 43.0'	122° 33.6'	59	BG, CT
43-4	37° 43.0'	122° 34.8'	59	BT, BG
44-1	37° 44.0'	122° 31.2'	39	BG
44-3	37° 44.0'	122° 33.6'	36	BT, BG
44-5	37° 44.0'	122° 36.0'	49	BT, BG, CT
44-6	37° 44.0'	122° 37.2'	69	BG, CT
45-5	37° 45.0'	122° 36.0'	39	BG
45-6	37° 45.0'	122° 37.2'	59	BG

[a]BT - Bottom trawl
BG - Bottom grab
CT - Crab trap

Survey Dates

Crab trapping and benthic infaunal survey cruises were made on July 10-11, 1973, October 30-31, 1973 and February 14-15, 1974. Trawling surveys were made on July 17 and 18, 1973; October 16, 1973; and April 5, 1974. Sampling dates were chosen to coincide with the major oceanographic periods so that seasonal changes in the benthic fauna could be assessed. As discussed in Volume I of the Predesign Report on Marine Waste Disposal (Brown and Caldwell, 1971), the oceanographic year can be divided into the Rainy Season and the Dry Season. Although these seasons are meteorological and not oceanographic periods per se, the seasonal changes in the freshwater outflow from San Francisco Bay are important enough to warrant this division. The Dry Season may be further divided into the Upwelling or Fog Period and Oceanic Period. The surveys made in July and October, 1973 coincided with the Upwelling and Oceanic Periods, respectively, and the February and April, 1974 surveys were made during the Rainy Season.

Sampling Equipment and Procedures

The sampling equipment and procedures used for sediment and benthic infaunal grabs, bottom trawls, and crab trapping are described below.

Sediment Samples. Three grab samples were collected at each station for analyses of benthic infauna on each of the three surveys. On the October 1973 and February 1974 surveys, an additional sample was collected and analyzed for various physical and chemical constituents.

The R/V Falcon, an 85-foot converted AVR, was used on the July 1973 survey, and the R/V Alert, a 125-foot ex-Coast Guard cutter, was used on subsequent surveys. All sediment samples were collected with a Shipek bottom sampler (Fig. 4-2). The Shipek sampler was chosen as it was the only sampler readily available which proved to be capable of obtaining a sediment sample in this area. More elaborate sampling equipment was not deemed necessary within the scope of the study.

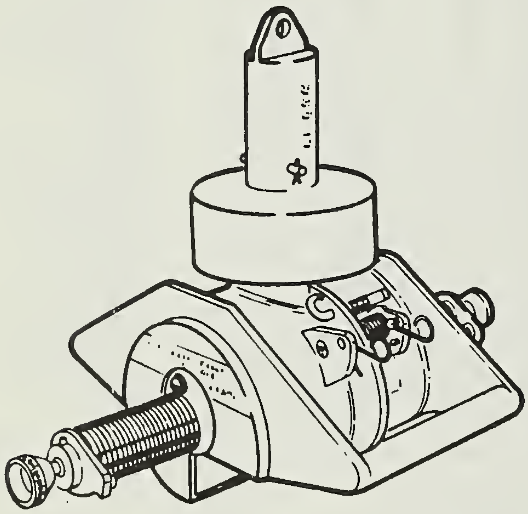


Fig. 4-2. Shipek Bottom Sampler

The purpose of collecting three samples at each station was to obtain information on the distribution of benthic invertebrates in the study area. The position of each sampling station was fixed using a Loran navigational system and radar, then the boat was allowed to drift so that each set of replicate samples was collected on a transect rather than at a fixed point. It has been shown (Jones, 1961) that both the number of organisms and the species composition of the fauna can vary among replicate samples even when the grabs are taken at points close together.

The Shipek bottom sampler used on these surveys theoretically sampled a section 0.195 meter on a side for a total area of 0.04 square meter. There was no way to measure the area actually sampled, since the sediment surface did not remain intact when the sample was brought aboard. Therefore, the sample volumes were recorded for each replicate as a substitute measure. These data are summarized in the appendix.

Bottom Trawls. The sampling gear used in bottom trawls was a 42-foot (head-rope) crab sampling net (Fig. 4-3). The body of the net was constructed of 1-1/4 inch mesh (stretch measurement) with a 1/2 inch liner in the cod end. The foot-rope of the net (lead line) was weighted with 16 feet of 3/8 inch galvanized chain. Sampling was conducted from the 65 foot commercial trawler, Q.T. The trawler's gear used included a pair of 3-1/3 foot by 6 foot steel otter boards connected to the net by a pair of 450 foot wire bridles (mud ropes). The net was towed with a 10 to 1 scope (ratio of the length of the tow line to the depth at each station).

The direction of each trawl was kept constant among surveys and was selected on the basis of the shortest distance between the end of one trawl station and the beginning of another. Trawl speeds were from two to three knots depending on variations in the tidal current and direction.

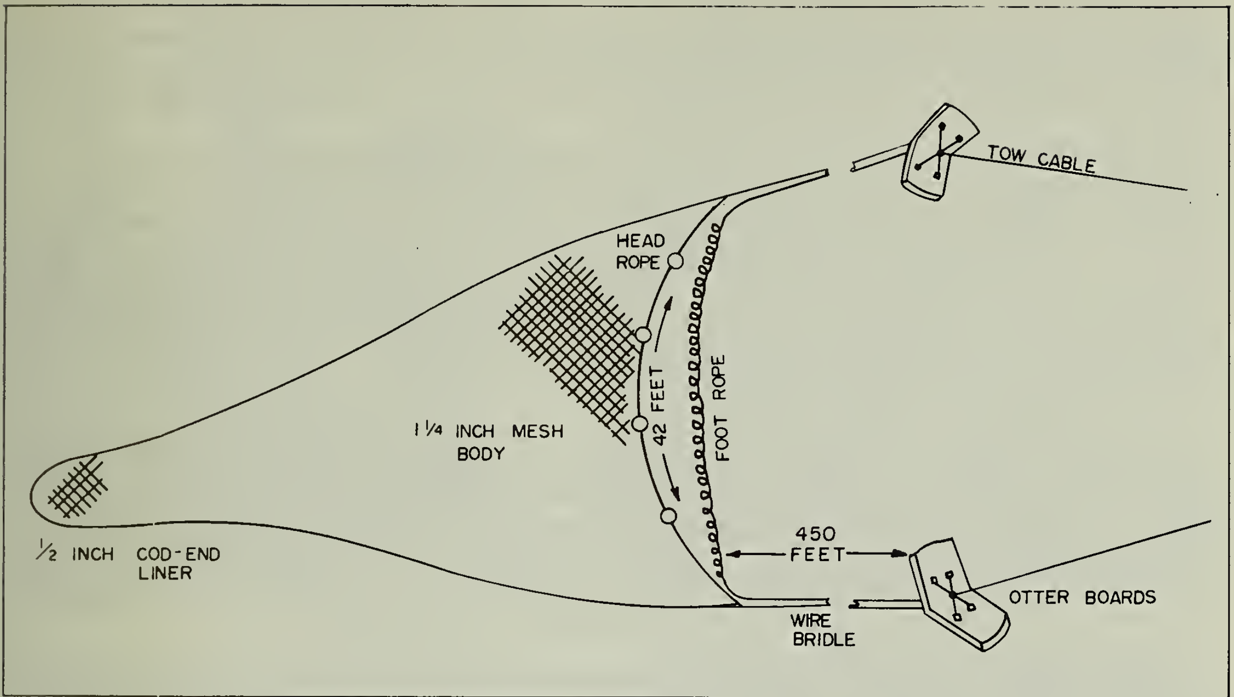


Fig. 4-3. Otter-Board Trawl Net with Commercial Gear

Trawling time was recorded from the time the collecting gear reached bottom and began fishing to the time the winch was started to haul in the net. On the July survey, the trawling time was ten minutes. During this survey, the entire catch in the first six trawls was saved, but because of the enormity of the combined catches, subsamples were taken from the remaining six trawl catches. After consultation with the DFG staff in both Monterey and Menlo Park, the trawl time was shortened to five minutes in the subsequent October 1973 and April 1974 surveys. Analyzing the entire catch of a five-minute trawl was judged superior to the subsampling of a ten-minute trawl, since it would reduce the errors inherent in this procedure. Both a five-minute and ten-minute trawl were made at Station 41.5-3 during the October 1973 and April 1974 surveys. A comparison of the findings is presented in the appendix.

The amount of fishes subsampled in the July 1973 survey was dependent on the size of the individual catch, ranging from 25 to 50 percent of the catch of each trawl. The subsampling procedure consisted of pouring the catch from the trawl net into eight boxes, removing the larger fishes (i.e., sharks and skates) from the catch and distributing the remaining fishes as evenly as possible into the boxes. The large fishes were identified as to species, sexed, measured and weighed before they were released. All Dungeness crabs were removed before the remainder of the catch was released.

Certain qualifications must be considered in any interpretation of the trawl data. It must be remembered that the program was intended to obtain general qualitative information on the benthic fish and invertebrate community inhabiting the study area. Because different sampling procedures were used, the data from different surveys cannot be compared. In addition, the data are influenced by the selectivity

of the sampling gear. This selectivity results from physical and biological characteristics of the organisms themselves, such as (1) their size with respect to the mesh size of the net; (2) their ability to avoid the net; (3) their schooling behavior; and (4) their proclivity to congregate by sex, by size class and by age class.

Two basic assumptions are made in analyzing the data collected. First, although catches obtained in five-minute and ten-minute trawls may differ in certain respects, the number of species or the number of individuals of a particular species is assumed to be a representive sample of the organisms available by bottom trawling with this type of net in the study area at that particular time. Second, it is assumed that subsamples taken from six of the trawl catches during the July 1973 survey reflected the entire catch composition. For comparision of catches, these subsamples are adjusted to 100 percent (the entire catch). .

Crab Trapping. The initial study plan called for eight crab traps to be set at each station; however, unforeseen difficulties necessitated some modifications. The commercial crab boat, Norene, used on the July 1973 survey, was not equipped with radar to locate the positions of stations so marker buoys were set at each station on the day before the traps were set. Inclement weather on the day of the survey made it impossible to find the marker buoys. Consequently, a single trapline with 72 traps was set; seventy-one traps were retrieved.

The October 1973 and February 1974 surveys were coordinated with the benthic infaunal surveys so that positions of stations could be fixed by the benthic survey vessel, the R/V Alert, which was equipped with radar and a Loran navigational system. However, adverse weather conditions still prevented setting and retrieving traps at all stations on these surveys. Eight traps were set at each of the nine stations on the October 1973 survey, but only 48 traps were recovered. Moreover, all traps were lost at stations 39-2, 42-1, and 44-5. On the February 1974 survey, traps were not set at stations 39-2, 39-4, and 42-1; forty-six of the 48 traps set at the remaining stations were recovered.

Standard 36-inch commercial crab traps were used for the study (Fig. 4-4). The two escape ports on each trap were wired shut to help prevent the escape of small crabs. The traps were baited with fresh rockfish carcasses suspended from the top of the trap and squid enclosed in perforated plastic bait containers which prevented the bait supply from being eaten by the captured crabs. Traps were set in lines with about 300 feet between traps. They were fished for 24 hours and then retrieved, except for two sets of eight traps on the February 1974 survey which were not retrieved for 48 hours because of inclement weather.

Sample Processing Procedures

The sample processing procedures used for sediment and benthic infaunal grabs, bottom trawls, and crab trapping are described below.

Sediments and Benthic Infaunal Samples. The samples for analysis of benthic infauna were sifted through a No. 35 screen (0.5 mm sieve opening). The organisms were then preserved in a 10 percent formalin-seawater mixture. A one percent rose bengal solution was added to the samples at a rate of 2.7 ml per liter. The purpose of this dye was to stain the animals bright red to facilitate examination. Prior to sorting and identification, the samples were rinsed with water in a No. 60 screen (0.25 mm sieve opening) to remove the formalin and excess dye. Organisms were then preserved in 40 percent isopropyl alcohol until analysis.

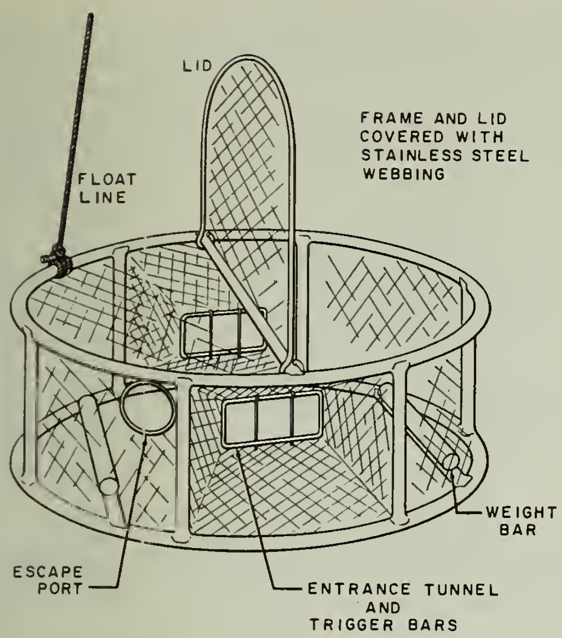


Fig. 4-4. Commercial Crab Trap

An extra 22 samples were collected in October 1973 and April 1974 for physical and chemical analyses. These samples were stored in glass jars and packed in dry ice in the field. They were then refrigerated in the laboratory until analysis. A portion of each sample to be analyzed for total organic carbon was kept frozen. No preservatives were added.

The animals in each sample were identified to species insofar as practicable using published keys. The taxonomic keys used for the identification are listed in the appendix. The entire sample was analyzed in each instance, and the results of the replicate samples were tabulated separately. The collection is now being curated and will be deposited at the California Academy of Sciences, San Francisco, California.

Particle size analyses were performed on an additional set of sediment samples collected from the October 1973 and February 1974 surveys. The purpose of these analyses was to characterize the sediments so that the different habitats could be correlated with the infaunal compositions. Since the sediments were found to be composed primarily of sand, only sieve analyses were performed. The procedures recommended by the American Society of Testing Materials (1972) were followed except that the sieves were those recommended by the United States Geological Survey (Guy, 1969). The percent sand and percent silt-clay were calculated on a weight basis for each sample.

Sediment samples were tested for selected heavy metals and chlorinated hydrocarbons. Cadmium, chromium, copper, lead, nickel, and zinc were analyzed for by atomic absorption spectroscopy (AAS), and mercury was analyzed for by flameless AAS. The chlorinated hydrocarbon analyzed for by gas chromotography included polychlorobiphenyls (PCB) and chlorinated hydrocarbon pesticides. The chlorinated hydrocarbons considered and the detection limits for each, expressed as mg/kg dry weight, are shown in Table 4-2. The analytical procedures, both for the heavy metals and for the chlorinated hydrocarbons, are in accordance with the procedures recommended by the U.S. Environmental Protection Agency (1974) and Standard Methods (1971).

Bottom Trawl Catches. All organisms collected in each bottom trawl, except Dungeness crabs, were sacked and labeled by station number. The Dungeness crabs were examined, measured, sexed and then released. The catch was iced and refrigerated immediately upon arrival at the laboratory.

The fishes were sorted according to species by station. Species identifications were confirmed by reference to Miller and Lea (1972), and museum collections when necessary. Representative specimens of each species were preserved in 10 percent formalin and will be deposited in collections at the California Academy of Sciences, San Francisco, California.

Table 4-2. Detection Limits of Chlorinated Hydrocarbons

Determination	Dry weight, mg/kg	Determination	Dry weight, mg/kg
Aldrin	0.010	Endrin	0.015
Alpha - BHC	0.010	Heptachlor	0.010
Chlordane	0.025	Heptachlor epoxide	0.010
P, P - DDD	0.015	Kelthane	0.015
DDE	0.010	Lindane	0.010
O, P - DDT	0.020	Methoxychlor	0.050
P, P - DDT	0.020	PCB's	0.10
Dieldrin	0.010	Thiodan	0.010
		Toxaphene	0.100

[a] Final detection by gas chromatography using an electron capture detector

Each fish was examined for superficial anomalies; however, records were kept of only those fishes with skin tumors (papillomas). These specimens were weighed, measured and preserved in 10 percent formalin.

All fishes were measured, and a total weight was obtained for each species by station. However, for large lots of similar sized individuals of a particular species, a subsample of 100 to 200 was measured and the remainder counted. Standard length measurements (i.e., tip of the snout to the end of the vertebral column) were made to the nearest millimeter. Total length measurements (tip of snout to the tip of the tail) were taken on all sharks, skates, and rays.

Fishes used for length-weight relationships were sorted for each station into size classes at 50 mm increments (i.e., 0-50, 51-100, etc.) until a maximum of 20 fishes were obtained for each size class. Standard length measurements (SL) were made to the nearest millimeter, and weights were recorded to the nearest gram.

Specimens were grouped in 10 millimeter intervals for analysis at the laboratory. This type of designation minimizes the effect of errors in the measuring of large numbers of fishes and the variations in lengths caused by shrinkage. Studies of larger commercial size English sole, petrale sole, and Dover sole showed that there was roughly a 5 mm difference in the measurement of these fishes when they were first collected and after they were packed in ice and refrigerated for two days (Harry, 1956).

Differentiation by sex for sex-length-weight relationships and sex ratios was made only for those species of fishes collected in the October 1973 and April 1974 surveys. This information was not collected during the July 1973 survey. Where sex could not be determined externally, a two-inch incision was made from the cloaca forward and the gonads removed for a visual determination.

Invertebrates were identified to the lowest taxon possible, using published keys, and enumerated. Crabs of the genus *Cancer* were identified as to species, sexed and measured. The size of crabs (shoulder width) is expressed as a caliper measurement of a straight line distance across the carapace immediately anterior of the outermost spines. Female Dungeness crabs were examined for eggs,and males were examined for mating marks on their claws. The relative hardness of the exoskeleton of male Dungeness crabs was observed and recorded as hard, filling or soft.

Specimens of Dungeness crab and the more abundant commercial species of fishes were selected from the catch and frozen for future analysis for PCB, .pesticides and heavy metals. Specimens were measured, weighed and identified as to species. Whenever possible, filets were taken, the skin discarded and the flesh ground to a homogenous paste using a blender. Where fishes were too small to filet, whole fishes were combined by species and homogenized. All the analyses were performed on wet tissue. A subsample of each was dried at 105 C overnight to determine percent total solids.

A five-gram aliquot of the homogenized paste was digested using an acid permanganate solution under refluxing condensers and analyzed by flameless atomic adsorption for mercury (Hatch and Ott, 1968).

A five-gram aliquot of each sample was also analyzed for copper, chromium, lead, nickel and zinc. This sample was digested with nitric acid and sulfuric acid, then diluted to volume and analyzed with an atomic absorption spectrophotometer. A deuterium arc background corrector was used to remove the effect of unwanted absorption and light scattering. The analytical procedure used was in accordance with the procedures recommended by the U.S. Environmental Protection Agency (1974) and *Standard Methods* (1971).

A 25-gram aliquot of each sample was analyzed for pesticides. The samples were extracted by methods prescribed by the Food and Drug Administration (1968). Final detection was by gas chromatography using an electron capture detector.

Crab Trap Catches. The crab trap catches were examined in the field so Dungeness crabs could be released alive. Crab species other than Dungeness crabs, as well as some fishes and other invertebrates, were also collected in the traps. Every organism was identified as to species, and selected specimens were retained for deposit in the reference collections of the California Academy of Sciences, San Francisco. Size data (shoulder width) were obtained for all crab species collected. Separate records were kept on the number of male Dungeness crabs with shoulder widths greater than 159 mm, since this is the minimum legal size that can be possessed by either commercial or sport fishermen. The catch processing procedures were the same as those used in processing the bottom trawl catches.

ANALYSIS OF THE SEDIMENTS

Data obtained on particle size and concentrations of heavy metals and chlorinated hydrocarbons are discussed in this section.

Particle Size

The particle size analyses revealed distinct patterns in the sediment composition. The silt-clay isopleths in Fig. 4-5 show that the surface sediments in the northeastern section of the grid are composed essentially of sand with a silt-clay fraction of less than five percent. This is as expected, since this section of the grid is located on the San Francisco Bar. The highest silt-clay fractions were found in the mid-section of the sampling grid. Station 41.5-3 had the highest silt-clay fraction on both the October 1973 and February 1974 surveys with 21.5 and 44.3 percent, respectively. Sediments in the southern portion of the sampling grid had silt-clay fractions ranging from 5.3 to 20 percent in October 1973 and 7.7 to 22.3 percent in February 1974. Overall it seemed that there was a greater percentage of sand in the surface sediments in October 1973 than in February 1974. The samples were not collected from the exact same locations so some of the differences can be attributed to sampling error. In addition, this relatively shallow area is subject to considerable turbulence because of wave action and is influenced to some degree by outflow from San Francisco Bay. It is expected, therefore, that there would be some seasonality in the sediment characteristics.

Heavy Metals and Chlorinated Hydrocarbons

The results from the chemical analyses of sediment samples collected in the October 1973 and February 1974 surveys (Tables 4-3 and 4-4, respectively) do not show any distribution patterns for the parameters tested. For example, the lowest concentration of cadmium observed in the October 1973 survey was 0.39 mg/kg (Station 42-6) and occurred with a silt-clay fraction of 20.8 percent. By contrast, in the February 1974 survey, the lowest concentration of cadmium obtained was 0.53 mg/kg (Station 39-1), and occurred with a relatively low silt-clay fraction of 7.7 percent. The results of the other heavy metals analyses were similarly variable. The concentrations of chromium, copper, and mercury varied without any apparent relationship to the silt-clay fraction in the sediments. The concentrations of lead, nickel, and zinc remained relatively constant at all stations. Concentrations of chlorinated hydrocarbons, including polychlorinated biphenyls, DDT and its breakdown product DDE, remained relatively constant at all stations and were usually at the lower detection limits. None of the other chlorinated hydrocarbon pesticides listed in Table 4-2 was detected.

The only stations that could obviously be expected to show evidence of contamination are stations 42-1 and 43-1 which are adjacent to the North San Mateo County Sanitation District outfall. The discharge from the outfall is approximately 5 mgd and comes from the primary treatment plant serving the Daly City area. The diffuser extends 2,500 feet from shore and was opposite Station 43-1. It is important to note that the concentrations of heavy metals and chlorinated hydrocarbons in the surface sediments at stations 42-1 and 42-3 did not differ significantly from the concentrations found several miles offshore. However, this is a domestic wastewater effluent discharge and would not be expected to exhibit extremes of chlorinated hydrocarbons or heavy metals.

Since data on heavy metals and chlorinated hydrocarbon concentrations are baseline, it is difficult to make value judgments with respect to particular concentrations. For comparative purposes the heavy metals data from this study have been summarized in Table 4-5 along with data on near shore sediments from other areas. The Southern California Coastal Water Research Project (SCCWRP, 1973) report represents estimated background concentrations of heavy metals in sediments near five major discharges in Southern California. These data represent the

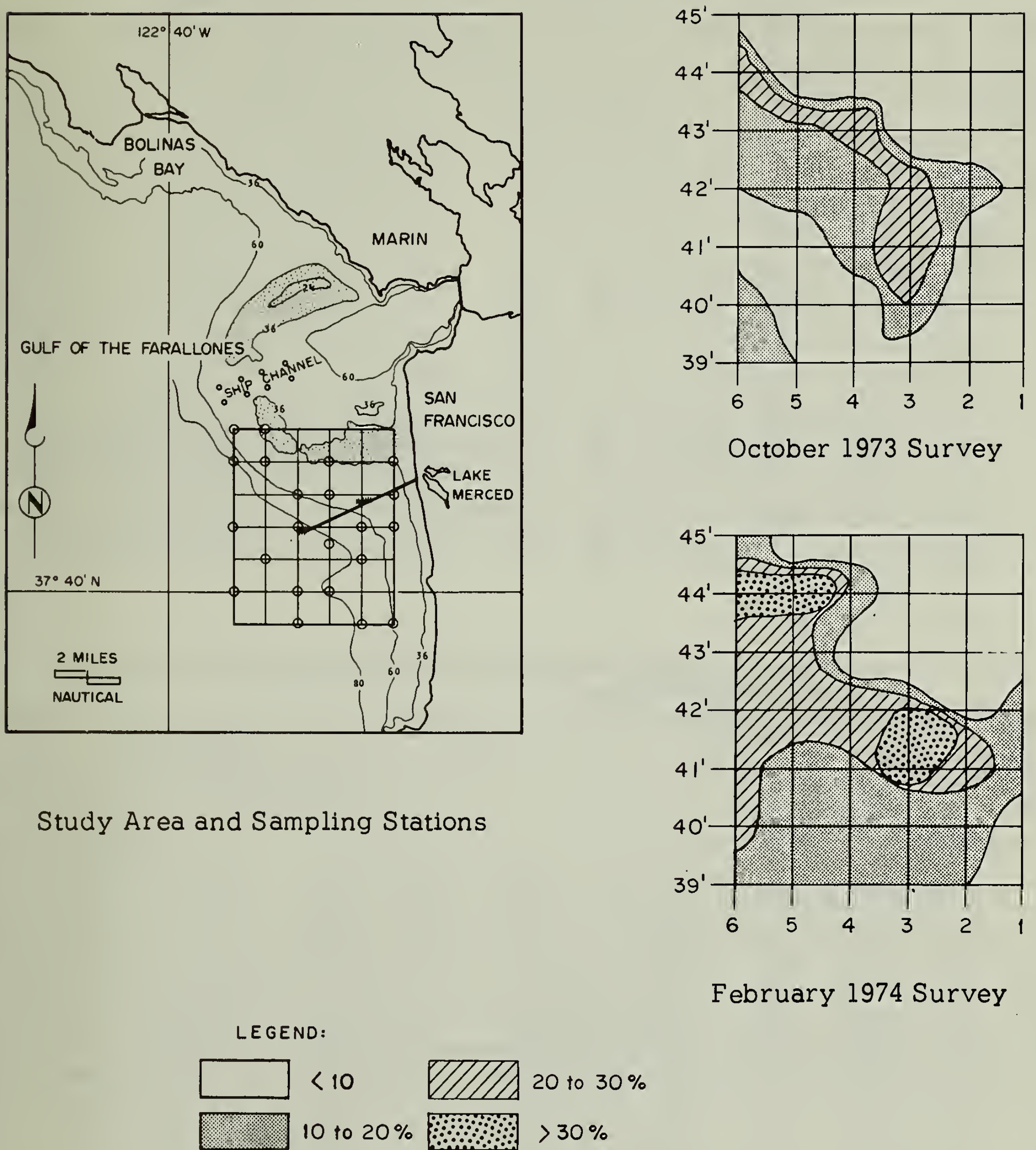


Fig. 4-5. Percent Silt-Clay in Surface Sediments, Gulf of the Farallones

analyses of the bottom layers of sediment cores collected near the discharges. It was assumed that the bottom sediment layers were deposited prior to the wastewater discharge. The SCCWRP study also found that concentrations of heavy metals were generally higher in surface sediments near wastewater discharges than in background areas away from the discharges.

Table 4-3. Heavy Metals in Sediments (mg/kg Dry Weight), Gulf of the Farallones

Station	October 1973							February 1974						
	Cd	Cu	Cr	Hg	Ni	Pb	Zn	Cd	Cu	Cr	Hg	Ni	Pb	Zn
39-1	1.02	5.6	51	0.033	40	13	30	1.30	6.1	50	0.038	38	10	31
39-2	0.52	6.8	59	0.035	46	11	38	0.69	6.2	55	0.036	47	9	34
39-4	0.81	6.5	63	0.024	45	9.4	38	0.72	6.5	60	0.028	44	11	36
40-3	1.06	7.2	54	0.031	45	11	38	0.64	6.4	54	0.026	48	11	37
40-4	0.68	6.4	66	0.116	44	11	39	0.76	6.9	66	0.022	48	12	38
40-6	0.80	6.7	57	0.032	43	8.6	40	0.78	7.0	67	0.023	48	12	40
41-2	0.80	6.7	58	0.032	45	9.4	37	0.90	8.1	57	0.050	49	12	39
41-5	0.82	6.3	53	0.184	38	9.5	39	0.71	6.4	48	0.026	42	11	37
41.5-3	0.56	8.4	54	0.048	50	12	43	0.83	8.7	59	0.081	51	14	41
42-1	0.77	7.2	62	0.102	40	10	37	0.93	7.0	58	0.079	49	10	37
42-2	0.64	7.7	56	0.077	46	11	42	1.13	7.6	66	0.075	53	11	40
42-4	0.55	8.2	68	0.043	48	13	43	0.60	6.8	45	0.048	44	10	37
42-6	0.39	7.8	56	0.033	47	11	42	0.58	6.6	53	0.062	45	10	36
43-1	0.84	7.2	76	0.024	48	11	38	0.72	6.3	46	0.038	48	8	34
43-3	1.13	7.6	114	0.034	51	12	40	0.73	6.3	65	0.035	46	10	34
43-4	0.66	8.9	57	0.064	53	14	41	0.87	7.2	56	0.044	46	11	38
44-1	0.53	5.9	72	0.072	43	10	33	0.61	5.7	144	0.018	43	10	38
44-3	0.69	6.0	77	0.023	47	12	34	0.69	6.2	102	0.028	45	11	38
44-5	0.43	7.3	95	0.034	51	11	40	0.53	8.5	48	0.066	50	12	41
44-6	1.51	9.1	52	0.084	54	13	42	0.83	8.7	60	0.062	52	14	40

Table 4-4. Chlorinated Hydrocarbons in Sediments (mg/kg Dry Weight), Gulf of the Farallones

Station	October 1973						February 1974					
	Polychlorobiphenyls				DDE	DDT	Polychlorobiphenyls				DDE	DDT
	1242	1248	1254	1262			1242	1248	1254	1262		
39-1	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
39-2	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
39-4	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	0.06	<0.05	<0.05	<0.05	<0.03	<0.03
40-3	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	0.06	<0.05	<0.05	<0.05	<0.03	<0.03
40-4	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
40-6	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	0.05	<0.05	<0.05	<0.05	<0.03	<0.03
41-2	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	0.07	<0.05	<0.05	<0.05	<0.03	<0.03
41-5	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	0.05	<0.05	<0.05	<0.05	<0.03	<0.03
41.5-3	0.06	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
42-1	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
42-2	0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
42-4	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
42-6	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
43-1	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
43-3	<0.03	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
43-4	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
44-1	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
44-3	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
44-5	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
44-6	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03

The heavy metals concentrations found in the Gulf of the Farallones are similar to background estimates from the SCCWRP report. Additional heavy metals data on near-shore sediments, obtained from Wodepohl (1960) as cited by Riley and Skirrow (1965), are listed in Table 4-5. The fact that these concentrations are higher than those in the SCCWRP study and in the present study demonstrates the variability of heavy metals concentrations.

Table 4-5. Comparison of Background Concentrations (mg/kg Dry Weight) of Heavy Metals in Near-Shore Sediments

Determination	Gulf of the Farallones		SCCWRP data,[a] mean	Representative near-shore sediments[b]
	October 1973 mean ± std. dev.	February 1974 mean ± std. dev.		
Cadmium (Cd)	0.76 ± 0.27	0.78 ± 0.19	0.37	--
Chromium (Cr)	65.0 ± 15.8	63.0 ± 22.6	46	100
Copper (Cu)	7.2 ± 1.0	7.0 ± 0.9	16	130
Lead (Pb)	11.1 ± 1.4	11.0 ± 1.5	8.5	20
Mercury (Hg)	0.056 ± 0.041	0.044 ± 0.020	0.037	--
Nickel (Ni)	46.2 ± 4.3	46.8 ± 3.6	14	55
Zinc (Zn)	38.7 ± 3.4	37.3 ± 2.6	63	--

[a]Data are estimated background concentrations of heavy metals in the sediments in the vicinity of five major Southern California discharge, taken from the Southern California Coastal Water Research Project report, 1973.

[b]Data are given as representative near-shore concentrations taken from Wodepohl (1960) in Chemical Oceanography, Volume 2 (Riley and Skirrow, 1965).

ANALYSIS OF THE BOTTOM TRAWL CATCHES

Discussed below are data obtained on benthic fishes and benthic invertebrates sampled in the bottom trawls.

Benthic Fishes

The benthic fishes collected in the trawl cruises are discussed below in terms of general composition, species distribution, and incidence of tumor-bearing fishes.

General Composition. Forty-eight species of fishes, representing 27 families, were collected during the study. A taxonomic list of these species is given in Table 4-6. Tables 4-7 and 4-8 summarize the species by total number and total weight, and percent composition by number and weight for each survey and the entire study.

Approximately 100,000 fishes were collected during the three surveys. Twelve species of benthic fishes comprised 87 percent of the total number of fishes collected (85,993 individuals). Another 31 species of benthic fishes comprised 2.2 percent of the catch (3,233 individuals). The remaining 10.8 percent (10,794 individuals) were pelagic or midwater fishes. These included Pacific herring, northern anchovy, and three species of smelt (night-smelt, whitebait smelt, and longfin smelt). Species of pelagic fishes have been omitted from the data analysis because a bottom trawl does not adequately sample fishes of this type. These fishes may have been collected coincidentally during the raising and lowering of the net. Almost 11 percent of the catch was composed of pelagic species, which may indicate a sizeable population of them in the study area. This fact is important because these fishes are important forage organisms, especially northern anchovy.

Table 4-6. Common and Scientific Names of Fishes Collected in Trawls, Gulf of the Farallones, 1973-1974

Scientific name	Common name
Family SQUALIDAE	
Squalus acanthias	Spiny dogfish
Family CARCHARHINIDAE	
Triakis semifasciata	Leopard shark
Mustelus henlei	Brown smoothhound
Family TORPEDINIDAE	
Torpedo californica	Pacific electric ray
Family RAJIDAE	
Raja binoculata	Big skate
Raja inornata	California skate
Family MYLIOBATIDIDAE	
Myliobatis californica	Bat ray
Family ACIPENSERIDAE	
Acipenser medirostris	Green sturgeon
Family CLUPEIDAE	
Clupea harengus pallasii	Pacific herring
Family ENGRAULIDIDAE	
Engraulis mordax	Northern anchovy
Family OSMERIDAE	
Spirinchus starksi	Night smelt
Allosmerus elongatus	Whitebait smelt
Spirinchus thaleichthys	Longfin smelt
Family BATRACHOIDIDAE	
Porichthys notatus	Plainfin midshipman
Family OPHIDIIDAE	
Chilara taylori	Spotted cusk-eel
Family MERLUCCIIDAE	
Merluccius productus	Pacific hake
Family GADIDAE	
Microgadus proximus	Pacific tomcod
Family SYNGNATHIDAE	
Syngnathus leptorhynchus	Bay pipefish
Family SCORPAENIDAE	
Sebastes auriculatus	Brown rockfish
Family ZANIOLEPIDIDAE	
Zaniolepis latipinnis	Longspine combfish
Family HEXAGRAMMIDAE	
Ophiodon elongatus	Lingcod
Family COTTIDAE	
Leptocottus armatus	Staghorn sculpin
Family AGONIDAE	
Occella verrucosa	Warty poacher
Stellerina xyosterna	Pricklebreast poacher
Odontopyxis trispinosa	Pygmy poacher
Family LIPARIDIDAE	
Liparis pulchellus	Showy snailfish
Family SCIAENIDAE	
Genyonemus lineatus	White croaker
Family EMBIOTOCIDAE	
Rhacochilus toxotes	Rubberlip surfperch
Zalembius rosaceus	Pink surfperch
Hyperprosopon anale	Spotfin surfperch
Cymatogaster aggregata	Shiner surfperch
Damalichthys vacca	Pile surfperch
Phanerodon furcatus	White surfperch
Family AMMODYTIDAE	
Ammodytes hexapterus	Pacific sandlance
Family STROMATEIDAE	
Peprilus semillimus	Pacific butterfish
Family CYNOGLOSSIDAE	
Symphurus atricauda	California tonguefish
Family BOTHIDAE	
Paralichthys californicus	California halibut
Citharichthys sordidus	Pacific sanddab
Citharichthys stigmaeus	Speckled sanddab
Family PLEURONECTIDAE	
Lepidopsetta bilineata	Rock sole
Pleuronichthys decurrens	Curlfin turbot
Pleuronichthys verticalis	Hornyhead turbot
Psettichthys melanostictus	Sand sole
Parophrys vetulus	English sole
Platichthys stellatus	Starry flounder
Glyptocephalus zachirus	Rex sole
Microstomus pacificus	Dover sole
Eopsetta jordani	Petrale sole

[a] Common and scientific names taken from Miller and Lea, 1972.

The families of fishes having the highest numbers of species represented were the pleuronectids or right-eyed flatfishes (nine species), and the embiotocids or surfperches (six species). Pleuronectids composed 28.0 percent of the total number of fishes caught (28,132 individuals) and 55.4 percent of the total weight of the catch (2632.2 kg). Embiotocids made up 5.2 percent (5,037 individuals) by number and 1.9 percent (84.7 kg) by weight of the total catch, respectively.

Table 4-9 shows the major species of fishes based upon frequency of occurrence, biomass, and number. All twelve species listed were collected on all three surveys and were found in six or more trawls on each survey. Together, these species were found in at least 24 of the 36 trawls, composing 87.1 percent by number and 86.2 percent by weight of the total catch. Five species were found in at least 35 of the 36 trawls; these were English sole, speckled sanddab, staghorn sculpin, Pacific tomcod, and sand sole. The three most numerous species composed 66.4 percent or 66,829 individuals. Ranked by number, Pacific tomcod was first, English sole second, and speckled

sanddab third, whereas by weight they ranked eighth, first and sixth, respectively. The Pacific sanddab was second and the big skate was third when ranked by weight.

Table 4-7. Number and Weight of Fishes Collected in Trawls, Gulf of the Farallones

Species	July 1973[a]		October 1973		April 1974		Total	
	Number	Weight, kg	Number	Weight, kg	Number	Weight, kg	Number	Weight, kg
Pacific tomcod	17,772	70.9	5,763	56.0	1,873	20.3	25,408	147.2
English sole	16,261	1,352.1	5,227	224.2	3,650	512.3	25,138	2,088.7
Speckled sanddab	10,510	107.8	3,717	34.7	2,065	26.2	16,283	168.7
Pacific sanddab	5,306	540.7	311	23.3	429	30.7	6,046	594.7
Whitebait smelt	-	-	38	0.2	4,981	11.2	5,019	11.5
White croaker	685	95.5	2,527	70.5	1,673	93.6	4,885	259.6
Night smelt	1,290	4.5	1,970	8.0	-	-	3,260	12.4
Shiner surfperch	24	0.7	1,916	21.9	849	11.1	2,789	33.6
Spotfin surfperch	484	6.2	1,760	7.7	344	3.4	2,688	17.3
Northern anchovy	396	5.4	35	6.0	1,036	8.6	2,067	14.6
Plainfin midshipman	160	11.1	1,277	2.4	78	7.6	1,515	21.2
Sand sole	437	83.9	295	51.1	340	53.6	1,072	188.7
Curlfin turbot	765	100.8	146	27.7	128	21.2	1,039	149.7
Staghorn sculpin	417	44.5	391	27.1	178	14.0	986	85.7
Petrale sole	480	80.8	1	0.3	-	-	484	81.1
Big skate	190	120.8	50	31.2	107	146.4	347	298.5
White surfperch	86	11.1	207	14.4	4	0.4	297	25.9
Spiny dogfish	195	97.8	2	0.9	3	3.3	200	101.9
Pacific herring	170	1.0	21	0.1	6	0.3	197	1.4
Dover sole	129	29.4	-	-	-	-	129	29.4
Rex sole	114	18.7	-	-	1	0.2	115	18.9
Starry flounder	58	41.8	28	24.0	11	3.6	97	69.4
Lingcod	55	1.3	1	T	7	T	63	1.3
Brown rockfish	49	24.3	-	-	8	5.3	57	29.6
Pacific butterfish	39	0.6	2	T	13	0.2	54	0.8
California tonguefish	1	T	48	0.7	4	0.1	53	0.8
Longfin smelt	-	-	51	0.2	-	-	51	0.2
Hornyhead turbot	26	1.4	16	1.5	6	1.4	48	4.3
Pile surfperch	34	6.6	6	0.4	2	0.6	42	7.6
Pacific hake	39	47.9	-	-	-	-	39	47.9
Brown smoothhound	2	1.6	2	0.9	31	43.3	35	45.9
Bat ray	-	-	1	9.1	18	54.3	19	63.4
Spotted cusk-eel	7	0.2	5	0.1	1	T	14	0.2
Pricklebreast poacher	3	T	4	T	5	T	12	0.1
Rock sole	2	0.8	1	0.2	7	1.0	10	2.0
Warty poacher	2	T	7	T	-	-	9	T
Leopard shark	-	-	-	-	7	22.0	7	22.0
Showy snailfish	-	-	5	0.1	1	T	6	0.1
California halibut	2	14.1	1	2.1	2	2.1	5	18.3
Longspine combfish	4	0.2	-	-	-	-	4	0.2
California skate	3	5.0	-	-	-	-	3	5.0
Pink surfperch	3	0.1	-	-	-	-	3	0.1
Rubberlip surfperch	-	-	2	0.2	-	-	2	0.2
Pygmy poacher	2	T	-	-	-	-	2	T
Pacific sandlance	2	T	-	-	-	-	2	T
Pacific electric ray	1	2.7	-	-	-	-	1	2.7
Green sturgeon	1	2.4	-	-	-	-	1	2.4
Bay pipefish	-	-	1	T	-	-	1	T
Total	56,507	2,934.9	25,835	642.0	18,659	1,098.6	100,104	4675.5

[a]Calculated number and weight of fishes from aliquots

T (trace) represents weights less than 0.1 kg

The English sole appears to be the best species for future monitoring, since it was found at all twelve stations in each survey, it was second in abundance (25.1 percent of the total catch by number), and it composed 43.9 percent of the total weight of fishes collected. The English sole is also an important component of the local commercial fish catch.

Table 4-8. Percent Composition by Number and Weight of Fishes Collected in Trawls, Gulf of the Farallones

Species	July 1973		October 1973		April 1974		Mean	
	Number percent	Weight percent	Number percent	Weight percent	Number percent	Weight percent	Number percent	Weight percent
Pacific tomcod	32.0	2.4	22.3	8.7	10.1	1.8	25.2	3.1
English sole	28.9	46.0	20.2	34.9	19.7	46.1	25.0	44.7
Speckled sanddab	18.7	3.7	14.4	5.4	11.1	2.4	16.2	3.6
Pacific sanddab	9.4	18.4	1.2	3.6	2.3	2.8	6.0	12.7
Whitebait smelt	-	-	0.2	<0.1	26.9	1.0	5.0	0.2
White croaker	1.2	3.2	9.8	11.0	9.0	8.5	4.8	5.5
Night smelt	2.3	0.1	7.6	1.2	-	-	3.2	0.3
Shiner surfperch	0.1	<0.1	7.4	3.4	4.6	1.0	2.8	0.7
Spotfin surfperch	0.3	0.2	6.8	1.2	1.9	0.3	2.2	0.4
Northern anchovy	0.7	0.2	0.1	0.1	9.9	0.8	2.2	0.3
Plainfin midshipman	0.3	0.4	4.9	0.4	0.4	0.7	1.5	0.4
Sand sole	0.8	2.8	1.1	8.0	1.8	4.9	1.1	4.0
Curlfin turbot	1.4	3.4	0.6	4.3	0.7	1.9	1.0	3.2
Staghorn sculpin	0.7	1.5	1.5	4.2	1.0	1.3	1.0	1.8
Petrale sole	0.8	2.7	<0.1	<0.1	-	-	0.5	1.7
Big skate	0.3	4.1	0.2	4.9	0.6	13.2	0.3	6.4
White surfperch	0.1	0.4	0.8	2.2	<0.1	<0.1	0.3	0.5
Spiny dogfish	0.3	3.3	<0.1	0.1	<0.1	0.3	0.2	2.2
Pacific herring	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1
Dover sole	0.2	1.0	-	-	-	-	0.1	0.6
Rex sole	0.2	0.6	-	-	<0.1	<0.1	0.1	0.4
Starry flounder	0.1	1.4	0.1	3.7	0.1	0.3	0.1	1.5
Lingcod	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1
Brown rockfish	0.1	0.8	-	-	<0.1	0.5	0.1	0.6
Pacific butterfish	0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
California tonguefish	<0.1	<0.1	0.2	0.1	<0.1	<0.1	<0.1	<0.1
Longfin smelt	-	-	0.2	<0.1	-	-	<0.1	<0.1
Hornyhead turbot	0.1	<0.1	0.1	0.2	<0.1	0.1	<0.1	<0.1
Pile surfperch	0.1	0.2	<0.1	<0.1	0.1	<0.1	<0.1	0.2
Pacific hake	0.1	1.6	-	-	-	-	<0.1	1.0
Brown smoothhound	<0.1	<0.1	<0.1	0.1	0.2	3.9	<0.1	1.0
Bat ray	-	-	<0.1	1.4	0.1	4.9	<0.1	1.4
Spotted cusk-eel	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pricklebreast poacher	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Rock sole	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Warty poacher	<0.1	<0.1	<0.1	<0.1	-	-	<0.1	<0.1
Leopard shark	-	-	-	-	<0.1	2.0	<0.1	0.5
Showy snailfish	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
California halibut	<0.1	0.6	<0.1	0.3	<0.1	0.2	<0.1	0.4
Longspine combfish	<0.1	<0.1	-	-	-	-	<0.1	<0.1
California skate	<0.1	0.2	-	-	-	-	<0.1	0.1
Pink surfperch	<0.1	<0.1	-	-	-	-	<0.1	<0.1
Rubberlip surfperch	-	-	<0.1	<0.1	-	-	<0.1	<0.1
Pygmy poacher	<0.1	<0.1	-	-	-	-	<0.1	<0.1
Pacific sandlance	<0.1	<0.1	-	-	-	-	<0.1	<0.1
Pacific electric ray	<0.1	0.1	-	-	-	-	<0.1	0.1
Green sturgeon	<0.1	0.1	-	-	-	-	<0.1	<0.1
Bay pipefish	-	-	<0.1	<0.1	-	-	<0.1	<0.1

The average weights of all fishes collected in July 1973 and April 1974 were nearly equal, 52 and 58 grams per fish, respectively. However, the average weight observed in October 1973 was substantially lower, 29 grams per fish. The size range and median length of each species collected on each of the three surveys are shown in Table 4-10. One of the primary reasons for the lower average weight in October is the collection of large numbers of young-of-the-year of English sole, white croaker, and plainfin midshipman. There was also a higher percentage in the catch of smaller species, such as shiner surfperch, spotfin surfperch, and night smelt. Large numbers of juvenile and smaller fishes were collected in the July and April surveys. The influence of their

presence on the median length of all the fishes measured was neutralized by the collection of larger specimens of adult flatfishes, sharks, skates, and rays.

Table 4-9. Ranking of Fish Species in Trawl Catch by Frequency of Occurrence and Percent Composition by Number and Weight, Gulf of the Farallones

Species	Percent comp. by number	Percent comp. by weight	Frequency of occurrence, number of trawls			
			July 1973	October 1973	April 1974	Total
Pacific tomcod	25.2	3.1	12	12	11	35
English sole	25.0	44.7	12	12	12	36
Speckled sanddab	16.2	3.6	12	12	12	36
Pacific sanddab	6.0	12.7	10	10	7	27
White croaker	4.8	5.5	12	6	10	28
Shiner surfperch	2.8	0.7	9	11	12	32
Spotfin surfperch	2.2	0.4	12	8	11	31
Plainfin midshipman	1.5	0.4	12	8	11	31
Sand sole	1.1	4.0	12	11	12	35
Curlfin turbot	1.0	3.2	12	11	9	32
Staghorn sculpin	1.0	1.8	12	12	12	36
Big skate	0.3	6.4	12	10	11	33

Possible seasonal variations in the abundance and composition of the fishes are discussed in the appendix with respect to the five more commonly collected species: the Pacific tomcod, English sole, speckled sanddab, white croaker, and Pacific sanddab. This discussion in the appendix is based on length frequency measurements taken during this study and on a literature review. Also appended are data on relationships between length and weight for these species.

Species Distribution. There are three limitations in analyzing the data by station: (1) the small study area, (2) the relatively insignificant difference in depth (59 feet) between the shallowest and deepest stations, and (3) the limitations inherent in the method of sampling. The results of the trawl surveys in July and October 1973 and April 1974 are presented by station in the appendix.

As shown in Table 4-9, there were 12 species of fishes found in two-thirds of the combined number of stations from the three surveys, with six species composing 80 percent of the total catch by number, and eight species composing 80 percent of the total catch by weight. The remainder of the catch was composed of species which were apparently seasonal in their occurrence (e.g., Pacific hake), associated with specific habitats (e.g., showy snailfish), or less commonly caught (e.g., green sturgeon). These were insignificant to the total catch whether considered by number or by weight. The presence or absence of these incidental species was reflected in the variations in numbers of species from one station to another.

Table 4-10. Size Range; Median Size, and Sex Ratio of Fishes Collected in Trawls, Gulf of the Farallones

Species	July 1973			October 1973				April 1974			
	Number measured	Size range, mm	Median size, mm	Number measured	Size range, mm	Median size, mm	Sex ratio, M:F	Number measured	Size range, mm	Median size, mm	Sex ratio, M:F
Pacific tomcod	10,309	50-244	66	2,332	54-230	88	27:25	988	70-175	117	104:82
English sole	9,097	31-342	170	5,227	45-350	94	53:244	3,650	54-352	193	61:255
Speckled sanddab	5,431	25-150	89	2,847	30-119	82	208:189	2,065	32-126	89	225:168
Pacific sanddab	3,235	109-300	190	311	93-262	151	72:88	429	104-267	155	72:94
Whitebait smelt	-	-	-	38	47-123	90	-	426	42-127	62	-
White croaker	595	136-290	178	1,161	73-240	101	49:49	1,173	61-265	112	48:73
Night smelt	116	55-116	75	1,094	48-115	76	18:20	-	-	-	-
Shiner surfperch	19	57-115	102	1,887	51-98	74	61:95	845	60-102	77	98:224
Spotfin surfperch	299	43-158	74	1,775	34-139	55	85:133	344	55-118	74	116:152
Northern anchovy	80	50-153	119	32	72-154	118	-	45	81-152	119	-
Plainfin midshipman	121	77-210	168	91	27-171	51	-	78	132-276	178	18:60
Sand sole	258	59-390	259	295	40-365	182	131:81	340	61-405	146	133:61
Curlfin turbot	433	40-261	164	146	68-224	175	46:91	128	97-252	177	25:100
Staghorn sculpin	223	94-229	171	376	111-230	142	168:209	178	118-217	158	106:72
Petrale sole	368	64-326	203	1	210	-	0:1	-	-	-	-
Big skate	134	165-1040	344	50	175-716	331	27:23	107	183-1400	424	60:44
White surfperch	44	113-223	173	199	70-233	106	18:92	4	148-192	154	4:0
Spiny dogfish	105	241-1125	479	2	284-560	-	0:2	3	470-800	603	2:1
Pacific herring	39	61-155	69	21	73-84	78	-	5	151-173	169	-
Dover sole	91	100-338	234	-	-	-	-	-	-	-	-
Rex sole	85	205-295	252	-	-	-	-	1	286	-	-
Starry flounder	37	210-500	268	28	245-466	297	11:13	11	205-293	246	7:4
Lingcod	46	80-315	105	1	139	-	-	7	73-80	76	-
Brown rockfish	25	158-320	237	-	-	-	-	8	200-320	253	7:1
Pacific butterfish	27	62-173	79	2	69-72	-	-	13	69-115	78	-
California tonguefish	1	75	-	48	81-162	100	-	4	71-120	85	-
Longfin smelt	-	-	-	50	55-107	67	-	-	-	-	-
Hornyhead turbot	10	70-195	97	16	118-197	132	7:2	6	148-242	172	3:3
Pile surfperch	17	82-260	185	6	96-182	115	-	2	232-233	-	1:1
Pacific hake	42	433-653	520	-	-	-	-	-	-	-	-
Brown smoothhound	1	657	-	2	510-696	-	1:1	31	420-850	740	8:23
Bat ray	-	-	-	1	1060	-	-	18	392-970	811	4:1
Spotted cusk-eel	4	160-200	173	5	106-215	124	-	1	141	-	-
Pricklebreast poacher	3	43-95	45	4	101-112	106	-	5	101-118	113	-
Rock sole	1	276	-	1	206	-	0:1	7	155-233	217	4:3
Warty poacher	1	125	-	7	45-69	65	-	-	-	-	-
Leopard shark	-	-	-	-	-	-	-	7	760-1400	830	-
Showy snailfish	-	-	-	5	82-135	119	-	1	159	-	1:1
California halibut	2	425-870	-	1	490	-	1:0	2	230-465	-	-
Longspine combfish	6	154-181	163	-	-	-	-	-	-	-	-
California skate	2	518-540	-	-	-	-	-	-	-	-	-
Pink surfperch	3	90-113	109	-	-	-	-	-	-	-	-
Rubberlip surfperch	-	-	-	2	108-168	-	0:2	-	-	-	-
Pygmy poacher	2	32-62	-	-	-	-	-	-	-	-	-
Pacific sandlance	1	110	-	-	-	-	-	-	-	-	-
Pacific electric ray	1	530	-	-	-	-	-	-	-	-	-
Green sturgeon	1	770	-	-	-	-	-	-	-	-	-
Bay pipefish	-	-	-	1	21	-	-	-	-	-	-

The analyses of sediment samples collected from the various stations show that the substrate over the study area is predominently sand. It is not surprising, therefore to find a predominance of flatfish, since they are particularly adapted to such bottoms. Since the study area offers little shelter, the majority of the fishes are probably there foraging for food. The relative number of individuals of a species and the relative number of species found in a given location in the study area would, therefore, be determined by the availability of food in that specific location. For example, relatively few benthic invertebrates, either by number of species or by number of individuals were collected on the San Francisco Bar itself. Fishes which feed on these animals would therefore not be expected to occur there except on a transient basis (see section entitled Benthic Infaunal Grabs).

Although it was not possible to precisely define the habitats throughout the study area, the presence of certain species such as showy snailfish and brown rockfish suggests the occurrence of microhabitats (e.g., sunken boats, rock outcrops, seaweed) that harbor species not commonly found over flat sand bottoms.

In order to analyze differences between stations and evaluate the relative contribution of each station to the total fish catch for the study area, the stations were ranked with respect to the following three criteria: (1) number of species collected, (2) total number of fishes collected, and (3) total weight of fishes collected.

Relatively large numbers of species were collected at stations 40-6 and 41-5 in July, 43-4 and 41-2 in October, and 40-3 and 41.5-3 in April (Table 4-11). Stations 40-6 and 41-5 in July each had a total of 25 species with 22 species in common. Stations 43-4 and 41-2 in October had a total of 20 and 21 species, respectively, with 15 species in common. The differences between these stations in the total number of species can best be attributed to chance collection of the less commonly collected solitary and schooling species of fishes. The stations having the highest species diversity in all three surveys were stations 41.5-3 and 41-5, followed by Station 40-3.

Table 4-11. Relative Contribution of Each Trawl Station to the Overall Catch in the Study Area, Gulf of the Farallones

Station	Number of species			Percent composition by number			Percent composition by weight		
	July 1973	October 1973	April 1974	July 1973	October 1973	April 1974	July 1973	October 1973	April 1974
41.5-3	24	16	19	16.0	16.6	8.9	15.2	10.0	10.7
40-3	24	14	21	23.1	5.0	21.9	12.9	6.8	23.7
41-2	17	20	18	5.8	15.1	5.4	9.1	19.8	11.6
40-6	25	14	17	6.1	7.9	6.7	7.0	7.3	7.7
41-5	25	17	16	5.3	7.3	5.6	3.4	6.7	6.0
40-4	21	16	14	11.2	2.2	13.6	19.0	2.0	8.6
39-4	23	10	16	8.9	0.8	7.5	12.8	0.7	10.4
44-5	22	17	14	3.8	10.2	11.2	1.6	7.3	6.7
43-1	19	18	18	5.3	4.1	3.2	7.4	6.4	5.6
42-6	20	16	15	6.3	4.8	14.2	3.7	6.3	6.2
44-3	20	18	15	5.2	2.7	1.0	7.3	7.3	2.5
43-4	20	23	10	2.4	23.3	0.8	1.4	19.4	0.3

Stations 41.5-3, 40-3 and 42-6 ranked first, second and third, respectively, in the total number of fishes collected. However, these stations ranked second, third and twelfth, respectively in total weight of fishes collected. Station 41-2 ranked first in weight. Based on the three criteria the stations contributing most to the total fish catch for the entire study area were 41.5-3, 40-3 and 41-2.

Tumor-Bearing Fishes. Tumors on various species of fishes, predominantly flatfishes, have been the subject of considerable research in recent years. Several authors infer that a causal relationship may exist between the incidence of tumors and environmental factors, but they present no concrete evidence (Cooper and Keller, 1969; McArn et al., 1968). One of the earliest references to tumorous fishes was made by Herald and Innes (manuscript, 1965) who stated that in 1922 wart-like dermal swellings were observed on juvenile English sole collected in San Francisco Bay by Carl L. Hubbs. Recent studies in Southern California reported in SCCWRP (1973) concluded that the occurrence of tumor bearing fishes does not appear to be related to any unique local condition. Histological studies have attributed the presence of

tumors on fishes to a variety of causes such as parasites, bacteria, fungi and viruses (McArn, et al., 1968; Good, 1940; Pacis, 1932; Herald and Innes, manuscript, 1965; and Cooper and Keller, 1969).

Skin tumors were observed on two species of flatfishes, Pacific sanddab and English sole. Only one tumor-bearing Pacific sanddab was found during the present study. It was collected in the July 1973 survey at Station 41-5 (Table 4-12). This 245 mm specimen weighed 243 grams and had a tumor at the symphysis of its lower jaw. One tumor-bearing English sole was collected during the October 1973 survey, whereas 63 were collected in April 1974. Of those specimens collected in April, 55 were collected in one ten-minute trawl at Station 41.5-3 and represented 7.4 percent of the total catch of English sole for that trawl. A five-minute trawl at the same station and done first, yielded only four tumor-bearing English sole (1.0 percent of the catch of this species). The remaining four specimens were collected singularly at each of four stations (40-4, 43-4, 41-2, and 40-3).

Table 4-12. Tumor-Bearing Fishes Collected in Trawls, Gulf of the Farallones

Species	Survey	Station	Number tumor-bearing fish	Percent composition in catch
Pacific sanddab	July 1973	41-5	1	0.1
English sole	October 1973	41-5	1	0.1
	April 1974	41.5-3	55	7.4
	April 1974	41.5-3	4	1.0
	April 1974	40-4	1	0.2
	April 1974	43-4	1	4.8
	April 1974	41-2	1	1.4
	April 1974	40-3	1	0.1

The relatively higher incidence of tumor-bearing English sole in the April 1974 survey may be caused by an infection in the resident population. Cooper and Keller (1969) reported the spontaneous occurrence of as many as three tumors on a single fish in a matter of days. It was also possible that fishes immigrated to the study area from San Francisco Bay. High incidences of tumor-bearing English sole in the bay have been reported, ranging from 6 to 32 percent of the catch of this species in a single trawl (Herald and Innes, manuscript, 1965, Cooper and Keller, 1969).

The size of tumor-bearing specimens of English sole ranged from 100 to 180 mm SL, with a mean of 122 mm SL. In comparison, the size of normal English sole collected in the same trawls ranged from 50 to 340 mm SL, with a mean of 187 mm SL. Tumors have not been reported on English sole much longer than 200 mm and are rarely seen on fishes longer than 150 mm. This would suggest that there is a predisposition to having tumors early in life. Whether the tumors are lethal to the fish or disappear as the fish matures is not known. Any debilitation of the affected fish is dependent on the degree of infection.

Examination of the numbers of tumors on tumor-bearing English sole showed that 78 percent had one tumor, 18 percent had two tumors, and smaller percentages had three or more tumors. McArn, et al., (1968) reported as many as 109 tumors on a single specimen. No more than six tumors were found on any single fish in this study. Table 4-13 shows the locations of external tumors. The most commonly affected areas were the body proper (42.2 percent), the anal fin (20.5 percent) and the dorsal fin (19.3 percent). Tumors in these areas would probably not impair a fish to any great extent. However, some tumors were found which covered one or

both eyes or which were on the pectoral fin or caudal fin; such tumors would eventually cause some debilitation. Forty-eight percent of the tumors were found on the eyed side, 23 percent on the blind side, and 29 percent on both sides (usually associated with a fin). There were noticeable differences in length-weight relationships of normal and tumor-bearing fishes (see Fig. 4-6). For example, the weight of tumor-bearing fishes was 44 percent less than that of normal fishes at 100 mm SL and 30 percent less at 180 mm SL. This is in contradiction to the findings of Cooper and Keller (1969), who found no difference between the weights of tumor-bearing and normal fishes.

Table 4-13. Location of Tumors on English Sole Collected by Trawling in April 1974, Gulf of the Farallones

Location of tumor	Eyed side	Blind side	Both sides	Percent frequency of occurrence
Dorsal fin	3	1	12	19.3
Anal fin	3	4	10	20.5
Pectoral fin	1	2	-	3.6
Caudal fin	-	-	1	1.2
Head	8	3	-	13.2
Body	25	9	1	42.2
Total	40	19	24	-
Frequency of occurrence	48%	23%	29%	-

Benthic Invertebrates from Trawl Catches

Approximately 31 species representing five phyla of invertebrates were collected (Table 4-14). Most of these species were represented by fewer than 100 individuals and were collected in only one or two surveys (Table 4-15). Analyses of the catch of invertebrates are confined to the more abundant species: the sand dollar, *Dendraster excentricus*; species of shrimp of the genus *Crago*; and species of crab of the genus *Cancer*.

Catch Analyses. The sand dollar, *Dendraster excentricus*, was the most common invertebrate in the catch, accounting for 41.9 percent of the invertebrates collected (3,165 individuals). It was also the most abundant invertebrate in the July 1973 and April 1974 survey. This species was collected only at Station 44-3 during all three surveys. Their concentration at this one station cannot be explained with the available data; the associated physical and chemical data collected at this station do not distinguish it from the others.

Second were species of shrimp of the genus *Crago*, composing 37.7 percent (2,847 individuals) of the invertebrates collected. Shrimps of this genus are important forage organisms and were represented by at least four species: *Crago franciscorum*, *C. nigricauda*, *C. nigromaculata*, and *C. stylirostris*. The relative abundance of these species by station in each survey is indicated in Table 4-16.

The black spot shrimp, *Crago nigromaculata*, was the most abundant species of shrimp in all three surveys, and accounted for 93.5 percent of the individuals representing the genus *Crago*. The frequency of occurrence of egg-bearing individuals

of this species was 27 percent in July 1973 and 38 percent in October 1973. No differentiation of egg-bearing individuals was recorded for the April 1974 survey.

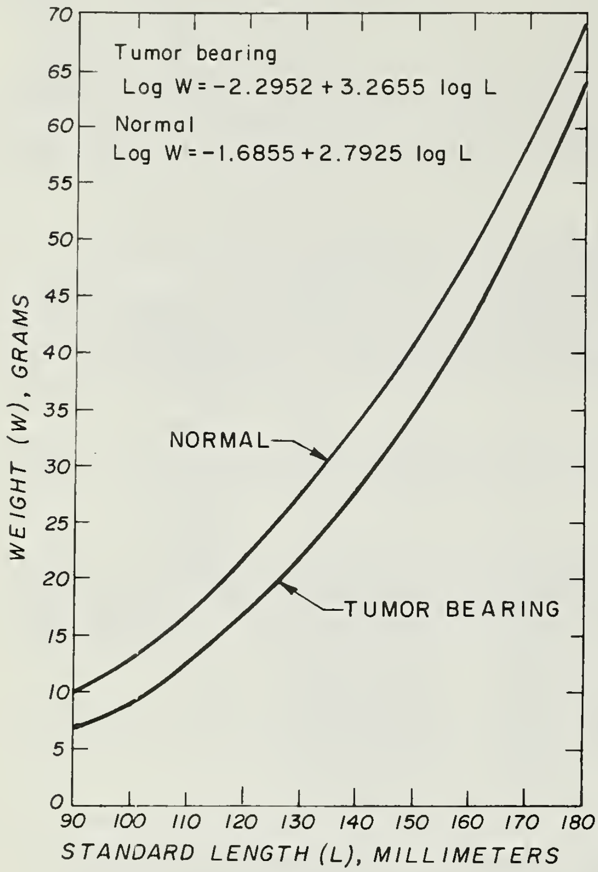


Fig. 4-6. Comparison of Length-Weight Relationship Curves Between Normal and Tumor-Bearing English Sole Collected by Trawling in April 1974, Gulf of the Farallones

The crab genus Cancer accounted for 13.9 percent of the invertebrates collected and was represented by three species, Cancer productus, C. gracilis, and C. magister.

The red crab, Cancer productus, was collected on only a few trawls (total of 10 individuals) and had a mean size (shoulder width) of 97 mm. The low incidence of this species in the October survey was of particular interest, since C. productus was one of the predominant species of this genus collected by crab trapping in that month (see section entitled, Analysis of the Crab Trap Catches). The predeliction of this species for rocky areas and burying itself in the sand (DFG, 1971) may make it unavailable for collection by trawling.

The slender crab, Cancer gracilis, was the most abundant species of this genus in the catches of the July and October surveys and overall (Table 4-15). A total of 606 slender crabs was collected. These crabs ranged in size (shoulder width) from 10 to 84 mm with an overall mean size of 45 mm (Table 4-17). The mean size overall and the mean size of each sex were similar for July and April, but was comparatively larger in October. The sex ratio (males to females) for July and April was also the same (2.5:1), whereas in October the sex ratio was 1.4:1. The overall sex ratio for the three surveys was 2:1. Males were slightly larger than females.

Dungeness Crabs. A total of 431 Dungeness crabs (Cancer magister) was collected with 155, 49, and 227 crabs being caught in July 1973, October 1973, and April 1974, respectively (Table 4-15). Several factors caused the numbers of crabs to substantially differ among the surveys. The most apparent factor is the change of trawl time from ten minutes in July to five minutes in the October and April surveys. The October catch was distinguished by the lack of both female and soft-shelled crabs. The sex ratios of male to female crabs were 5.2:1, 11.0:1, and 1.1:1, respectively for July, October and April (Table 4-18). Female Dungeness crabs spawn sometime between October and December and carry the eggs under their abdominal flap until they hatch. This occurs between November and February (DFG, 1971). During this period the egg-bearing females bury themselves in the sand and are seldom collected by trawling. Soft-shelled male crabs composed only seven percent of the catch in October, whereas in July and April, they made up respective percentages of 44.6 and 50. After maturity, male crabs normally molt once a year, during the summer. Therefore, most of these crabs would be expected to be hard-shelled by

October (Poole and Gotshall, 1965). According to Dahlstrom (Walter Dahlstrom, Biologist, DFG, personal communication, 1974), trawling appears to selectively catch a disproportionate number of soft-shelled crabs because of the inability of these crabs to bury into the sand as deeply as the hard-shelled crabs.

Table 4-14. Common and Scientific Names of Invertebrates Collected in Trawls, Gulf of the Farallones, 1973-1974

Scientific Name		Common Name	Scientific Name		Common Name
Phylum Arthropoda					
Tecticeps pugettensis	-	Isopod	*Stylatula elongata*	-	Sea pen
Lironeca vulgaris	-	Isopod	Phylum Annelida		
Crago sp.	-	Crago shrimp	*Nereis* sp.	-	Clam worm
Crago franciscorum	-	Bay shrimp	*Neanthes* sp.	-	Pile worm
Crago nigricauda	-	Blacktail shrimp	*Travisia gigas*	-	Annelid worm
Crago nigromaculata	-	Blackspotted shrimp			
Crago stylirostris	-	Sharpnose shrimp	Phylum Mollusca		
Pandalus danae	-	Coon-striped shrimp	*Solen sicarius*	-	Razor clam
Randallia ornata	-	Purple crab	*Tellina modesta*	-	Tellen clam
Cancer gracilis	-	Slender crab	Unindentified clam		
Cancer magister	-	Dungeness crab	*Nassarius fossatus*	-	Channel dogwhelk
Cancer productus	-	Red crab	*Nassarius perpinguis*	-	Fat dogwhelk
Chorilia longipes	-	Spider crab	*Polinices draconis*	-	Drake's moon-snail
Isochelis pilosus	-	Giant hermit crab	*Polinices lewisii*	-	Lewis moon-snail
Pagurus sp.	-	Hermit crab	Unindentified snail		
Phylum Echinodermata			*Octopus* sp.	-	Octopus
Dendraster excentricus	-	Sand dollar	*Loligo opalescens*	-	Common squid
Pisaster brevispinus	-	Short spine starfish			

The large catch of crabs in April was in part the result of a relative increase in the percentage of crabs between 90 and 120 mm collected. This increase may reflect a migration of crabs from San Francisco Bay, where large numbers of juveniles and subadults are reported to occur (Walter Dahlstrom, Biologist, DFG, personal communication, 1974). The mean size decreased from a high of 125.4 and 123.8 mm in July and October to a low of 107.4 mm in April. The lower mean size was in part caused by the absence of legal-sized crabs (159 mm) in the April catch. The study area was intensely fished by commercial crab fishermen between February and April 1974. For this reason the number of legal male crabs available for collection by trawling was reduced.

The shell condition of male Dungeness crabs is a description of the varying hardness of their shell (exoskeleton) and is used as a measure of the time since molting occurred. Information on molting is used to set the time of the commercial crab fishing season so that it coincides with the time when most crabs are hard and have the highest yield of meat. This allows for a maximum utilization of this resource. The exoskeleton of the crabs remains soft for several weeks after molting and does not completely harden for several months (Cleaver, 1949). Using the descriptions of Waldron (1958), a hard-shelled crab (Grade 1) has a rigid carapace and the exoskeleton of the legs is rigid or slightly pliable. A filling crab (Grade 2) has a slightly to moderately flexible carapace, and a soft-shelled crab (Grade 3) has a flexible carapace which can be crushed in the hand.

Table 4-15. Enumeration of Invertebrates Collected in Trawls, Gulf of the Farallones

Species	July 1973	October 1973	April 1974	Total
Stylatula elongata	-	-	2	2
Nereis sp.	-	-	1	1
Neanthes sp.	-	-	1	1
Travisia gigas	-	-	1	1
Tecticeps pugettensis	-	-	2	2
Lironeca vulgaris	P	P	P	P
Crago sp.	1	-	6	7
Crago franciscorum	6	157	-	163
Crago nigricauda	-	-	-	7
Crago nigromaculata	866	1311	474	2651
Crago stylirostris	1	-	17	18
Pandalus danae	-	-	1	1
Randallia ornata	1	-	1	2
Cancer gracilis	180	291	139	610
Cancer magister	154	48	230	432
Cancer productus	4	5	1	10
Chorilia longipes	-	-	1	1
Isochelis pilosus	30	17	1	48
Pagurus sp.	-	-	23	23
Solen sicarius	1	-	-	1
Tellina modesta	-	-	1	1
Unidentified clam	-	2	-	2
Nassarius fossatus	-	-	3	3
Nassarius perpinguis	26	-	4	30
Polinices draconis	37	50	3	90
Polinices lewisii	9	-	59	68
Unidentified snail	-	2	-	2
Octopus sp.	1	-	1	2
Loligo opalescens	1	74	1	76
Dendraster excentricus[a]	1152	129	1884	3165
Pisaster brevispinus	63	9	57	129
Total	2533	2095	2921	7546

[a]Dendraster excentricus was collected at Station 44-3 on all three surveys and no where else.
P - (present) - Lironeca vulgaris is an isopod which is found on the gill covers of fishes, therefore not enumerated.

Table 4-16. Catch Data by Station for Species of Crago Shrimp and Cancer Crab Collected in Trawls, Gulf of the Farallones

Species	Survey	39-4	40-3	40-4	40-6	41-2	41-5	41.5-3	42-6	43-1	43-4	44-3	44-5
Cancer gracilis	July 1973	14	12	4	-	46	-	19	-	22	11	31	21
	October 1973	6	65	47	1	6	5	90	1	1	36	5	28
	April 1974	15	20	24	9	16	19	5	10	8	1	2	10
C. magister	July 1973	6	3	20	1	-	1	46	4	16	1	19	37
	October 1973	-	-	-	3	6	1	3	1	2	7	4	21
	April 1974	1	-	2	1	9	3	50	6	2	64	13	79
C. productus	July 1973	-	-	-	-	-	-	1	-	2	-	1	-
	October 1973	-	1	-	-	-	-	-	1	-	1	1	1
	April 1974	-	-	-	-	-	-	1	-	-	-	-	-
Crago sp	July 1973	-	-	-	-	-	-	-	-	-	-	1	-
	April 1974	-	-	-	-	3	-	-	-	-	-	-	3
C. franciscorum	July 1973	-	-	-	-	-	-	-	-	-	-	-	6
	October 1973	1	1	-	-	-	-	-	-	2	144	4	5
C. nigricauda	April 1974	-	-	-	-	-	-	-	-	7	-	-	-
C. nigromaculata	July 1973	32	15	4	13	25	39	88	-	45	-	155	450
	October 1973	46	50	28	36	42	47	21	-	85	428	24	504
	April 1974	7	12	7	11	1	21	32	31	7	49	3	293
C. stylirostris	July 1973	-	-	-	-	-	-	-	-	-	-	1	-
	April 1974	-	-	-	-	-	-	-	-	17	-	-	-

Table 4-17. Catch Data for the Slender Crab, Cancer gracilis, Collected in Trawls, Gulf of the Farallones

Shoulder width, mm	July 1973 percent composition			October 1973 percent composition			April 1974 percent composition			Mean percent composition		
	Male	Female	Both	Male	Female	Both	Male	Female	Both	Male	Female	Both
10-19	-	-	-	-	-	-	1.0	15.8	5.2	0.2	2.9	4.5
20-29	0.8	5.9	2.2	1.2	3.3	2.1	9.3	36.8	17.0	3.0	1.0	5.4
30-39	21.7	51.0	30.0	1.8	5.0	3.1	12.4	26.3	16.3	10.9	2.0	14.0
40-49	39.5	35.3	38.3	21.2	44.6	31.0	11.3	10.5	11.1	24.7	36.2	28.7
50-59	18.6	5.9	15.0	50.6	50.6	48.1	40.2	10.5	31.8	37.6	29.0	34.6
60-69	10.8	2.0	8.3	19.4	2.5	12.4	21.6	-	20.7	17.2	1.9	11.9
70-79	8.5	-	6.1	5.3	-	3.1	4.1	-	3.0	6.1	-	4.0
80-89	-	-	-	0.6	-	0.3	-	-	-	0.2	-	0.2
Total	129	51	180	170	121	291	97	38	135	396	210	606
Mean size, mm	44	35	41	50	44	48	46	26	41	48	38	45
Sex ratio (M:F)	2.5:1			1.4:1			2.5:1			1.9:1		

The soft-shell condition indicates a recent molt. The filling condition is an intermediate stage in which the hardening carapace is filling with meat. Most adult males molt during the summer, whereas females molt during late spring to early summer; however it is possible to find crabs in various shell conditions throughout the year. This is especially true with respect to juvenile crabs, since they go through several molts in their first year. Male crabs mature when they are roughly 100 mm wide and 1-1/2 years old (Poole and Gotshall, 1965).

Table 4-18. Catch Data for the Dungeness Crab Collected in Trawls, Gulf of the Farallones

Shoulder width, 10mm size class	July 1973 percent composition			October 1973 percent composition			April 1974 percent composition			Total percent composition		
	Male	Female	Both	Male	Female	Both	Male	Female	Both	Male	Female	Both
10-19	2.3	-	1.9	2.3	-	2.1	-	-	-	1.3	-	0.9
20-29	6.1	-	5.2	-	-	-	-	-	-	2.7	-	1.9
30-39	1.5	-	1.3	9.2	-	8.3	-	-	-	2.0	0.8	1.4
40-49	-	-	-	2.3	25.0	4.2	0.8	2.9	1.7	0.7	3.0	1.4
50-59	0.8	-	0.6	-	-	-	1.6	1.9	1.7	1.0	2.3	1.2
60-69	-	-	-	-	-	-	0.8	-	0.4	0.3	-	<0.1
70-79	-	-	-	-	-	-	-	1.0	0.5	-	0.8	0.2
80-89	0.8	-	0.6	-	-	-	0.8	-	0.4	0.7	0.8	0.5
90-99	0.8	4.0	1.3	2.3	-	2.1	6.4	36.9	20.2	3.0	29.5	11.4
100-109	-	8.0	1.3	4.6	25.0	6.2	47.6	42.7	45.2	20.4	35.6	25.1
110-119	6.9	8.0	7.1	2.3	-	2.1	24.2	4.8	15.3	13.4	5.3	10.9
120-129	19.2	48.0	24.0	9.2	-	8.3	8.0	2.9	5.7	13.0	11.4	12.6
130-139	20.8	16.0	20.1	22.7	50.0	25.0	4.8	4.8	4.8	14.4	8.3	12.6
140-149	26.1	16.0	24.7	20.4	-	18.7	4.0	1.9	4.4	16.0	4.5	12.5
150-159	10.8	-	5.5	15.9	-	14.6	0.8	-	0.4	7.4	-	5.1
160-169	2.3	-	1.9	9.2	-	8.3	-	-	-	2.3	-	1.6
170-179	1.5	-	1.3	2.3	-	2.1	-	-	-	1.0	-	0.7
Total	130	25	155	45	4	49	124	103	227	299	132	431
Mean size, mm	125.4	125.2	125.3	123.8	105.7	122.3	109.2	105.2	107.4	118.4	109.0	109.0
Median size, mm	-	-	133.0	-	-	137.0	-	-	102.0	-	-	-
Sex ratio (M:F)	5.2 : 1			11.0 : 1			1.1 : 1			2.2 : 1		

Table 4-19 presents a summary of the shell conditions of the male Dungeness crabs. Most of the crabs in the July 1973 catch were soft-shelled. The smaller soft-shelled and filling crabs above 100 mm presumably had recently molted to the adult size. Since mating normally occurs from March to July between hard-shelled males and soft-shelled female crabs (Poole and Gotshall, 1965), it is not surprising to find that 82.1 percent of the hard-shelled adult males had mating marks on their chelipeds (claws). Ninety-three percent of the males in October were either hard-shelled or filling, which would suggest that they molted during the summer. However, the high percentage of males with mating marks (85 percent) among the hard-shelled males indicates that these crabs had either mated before July and had not yet molted, or there was an extended mating season. The high percentage of soft-shelled and filling crabs in the April survey suggests the recruitment of recently molted juveniles into the adult population.

Chemical Analysis of Fishes and Invertebrates

The results of the chemical analyses for PCB's, pesticides and heavy metals in Dungeness crabs and four species of commercial flatfishes (English sole, Pacific sanddab, sand sole and starry flounder) are appended. Since data on heavy metals and chlorinated hydrocarbon concentrations have not been previously collected, it is difficult to make value judgments with respect to particular concentrations.

Concentrations of all metals except zinc, chromium, copper, and mercury were below the detection limits of 0.1 mg/kg wet weight for both fishes and crabs from the October 1973 and April 1974 surveys. The higher concentrations of chromium and zinc in fishes were found in the composite samples of whole fishes. In Dungeness

crabs, chromium was found in only trace concentrations whereas zinc ranged from 26 to 49 mg/kg wet weight. Chromium concentrations in fishes ranged from 1.1 to 15 mg/kg. The concentrations of mercury and copper were generally low.

Table 4-19. Shell Condition of Male Dungeness Crabs Collected in Trawls, Gulf of the Farallones

Shoulder width, 10mm size class	July 1973				October 1973				April 1974			
	Hard	Filling	Soft	Mating marks	Hard	Filling	Soft	Mating marks	Hard	Filling	Soft	Mating marks
10-19	3	-	-	-	1	-	-	-	-	-	-	-
20-29	8	-	-	-	-	-	-	-	-	-	-	-
30-39	1	-	1	-	4	-	-	-	-	-	-	-
40-49	-	-	-	-	1	-	-	-	-	-	1	-
50-59	-	-	1	-	-	-	-	-	-	-	2	-
60-69	-	-	-	-	-	-	-	-	-	-	1	-
70-79	-	-	-	-	-	-	-	-	-	-	-	-
80-89	-	-	1	-	-	-	-	-	1	-	-	-
90-99	-	-	1	-	-	-	1	-	-	1	7	-
100-109	-	-	-	-	-	1	-	-	-	17	38	-
110-119	-	6	3	-	-	1	-	-	1	19	10	-
120-129	3	9	13	2	1	3	-	-	1	6	3	-
130-139	5	6	16	5	2	8	-	2	-	6	-	-
140-149	15	4	15	11	5	4	-	4	4	2	-	3
150-159	4	5	5	4	5	1	1	5	3	1	-	1
160-169	1	2	-	1	-	3	1	-	-	-	-	-
170-179	-	-	2	-	-	1	-	-	-	-	-	-
Total	40	32	58	23	19	22	3	11	10	52	62	4
Percent composition	30.8	24.6	44.6	82.1	42.2	48.9	6.7	84.6	8.1	41.9	50.0	44.4

ANALYSIS OF THE CRAB TRAP CATCHES

Data obtained from the crab trapping surveys are discussed below with respect to the general composition of the catches and an analysis of catch data for Dungeness crabs, red crabs, and fishes.

General Composition of Catches

Dungeness crabs constituted the majority of crabs collected on the three trapping surveys. Four other species of *Cancer* crabs and several species of fishes and invertebrates were also collected. Table 4-20 shows the number of organisms collected on each survey with both scientific and common names listed for each species. All the rock crabs (*Cancer antennarius*) and most of the yellow crabs (*Cancer anthonyi*) and red crabs (*Cancer productus*) were collected on the October 1973 survey. The slender crab, *Cancer gracilis*, was found mostly on the July 1973 survey. The starfish, *Pisaster brevispinus*, was found clinging to the traps on all surveys. Their presence was noted, but no counts were made.

Dungeness Crabs

The Dungeness crab catch data are summarized in Table 4-21. The largest catch was 817 crabs, collected on the July 1973 cruise; 219 of these were legal

males (159 mm). This is because more traps were retrieved on this survey (71) than on either of the subsequent surveys. However, the average catch per trap was also highest in July 1973 when either legal males or all crabs are considered. Only 48 traps were recovered in October 1973 and 46 traps in February 1974; the respective total catches were 226 and 346 crabs. The average numbers of legal males per trap were 1.2 and 1.5 in October and February, respectively, which are both markedly lower than the 3.1 average obtained in July. The relatively low catch per trap ratio of legal males in the February 1974 survey was probably the result of competitive fishing. A large number of commercial crab traps were observed in the study area during this time.

Table 4-20. Organisms Collected in Crab Traps, Gulf of the Farallones

Scientific name	Common name	July 1973	October 1973	February 1974
Invertebrates				
Cancer antennarius	Rock crab	-	4	-
Cancer anthonyi	Yellow crab	6	31	2
Cancer gracilis	Slender crab	14	-	1
Cancer magister	Dungeness crab	817	225	346
Cancer productus	Red crab	13	213	9
Isochelis pilosus	Giant hermit crab	1	-	-
Pisaster brevispinus	Small spine starfish	P	P	P
Fishes				
Citharichthys sordidus	Pacific sanddab	22	6	-
Parophrys vetulus	English sole	1	-	-
Psettichthys melanostictus	Sand sole	-	1	-
Sebastes auriculatus	Brown rockfish	5	6	6

The catch percentages of female Dungeness crabs fluctuated among the surveys with respective percentages of 16.6, 1.3, and 24.4 in July 1973, October 1973 and February 1974. The lower percentage of females in the October 1973 catch is consistent with the observation made by Dahlstrom (Walter Dahlstrom, Biologist, DFG, personal communication, 1974) that egg-bearing crabs apparently do not feed during the two to three months preceding hatching, and therefore are rarely collected in baited traps. Female crabs are egg-bearing sometime between October and December and spawn between November and February (DFG, 1971). Three females were collected on the October 1973 survey, and none of these were egg-bearing.

Distribution. Tables 4-22, 4-23, and 4-24 present the crab catch data by station. The July 1973 survey consisted of a transect divided into nine equal groups of eight traps each. The July 1973 survey data show that the traps in the deeper station groups collected more crabs of all categories than the shallower station groups. However, the October 1973 and February 1974 data, revealed no

relationship between depth and the number of crabs collected. The collection of crabs at all stations sampled on each survey indicates that crabs are widely distributed throughout the study area.

Table 4-21. Catch Data for the Dungeness Crabs Collected in Crab Traps, Gulf of the Farallones

Survey	No. of traps	Number of crabs				Catch per trap	
		Legal[a] males	Sublegal males	Females	Total	Legal males	Total
July 1973	71	219	462	136	817	3.1	11.5
October 1973	48	50	172	3	225	1.2	4.7
February 1974	46	70	193	83	346	1.5	7.5

[a]Legal commercial crab is 159 mm shoulder width

Table 4-22. Catch Data for Dungeness Crabs Collected in Crab Traps in July 1973, Gulf of the Farallones

Station	Depth, meter	No. of traps	Sublegal males	Legal males	Females	Total
1	19	8	5	3	3	11
2	21	8	37	14	5	56
3	21	8	35	7	9	51
4	21	8	49	15	13	77
5	22	7 [a]	59	24	15	98
6	23	8	70	50	16	136
7	25	8	85	34	28	147
8	26	8	72	40	17	129
9	28	8	49	32	30	111

[a]One trap was not recovered

Size. Shoulder width measurements of Dungeness crabs were grouped into five-millimeter size classes and plotted to show their size frequency distributions. The data for male and female crabs are plotted separately in Fig. 4-7 and 4-8, respectively. The size of male crabs shows a similar pattern for the three surveys, ranging from 115 to 191 mm shoulder width with the mean respective sizes being 154, 147, and 156 mm for the July 1973, October 1973 and February 1974 surveys.

The size frequency distributions for the female crabs are not comparable because only three female crabs were collected on the October 1973 survey. The mean shoulder widths for females in the July 1973 and February 1974 surveys were 144 and 147 mm, respectively, with an overall range of 121 to 181 mm. The three females collected in October 1973 had a mean shoulder width of 156 mm.

Table 4-23. Catch Data for Dungeness Crabs Collected in Crab Traps in October 1973, Gulf of the Farallones

Station	Depth, meter	No. of traps	Sublegal males	Legal males	Females	Total
39-2	24	-[a]	-	-	-	-
39-4	18	8	11	1	0	12
41-5	27	8	19	15	0	34
41.5-3	23	8	29	4	1	34
42-1	18	-[a]	-	-	-	-
42-6	27	8	35	9	1	45
43-3	18	8	48	11	0	59
44-5	15	-[a]	-	-	-	-
44-6	21	8	33	8	1	42

[a]No traps recovered from these stations

Table 4-24. Catch Data for Dungeness Crabs Collected in Crab Traps in February 1974, Gulf of the Farallones

Station	Depth, meter	No. of traps	Sublegal males	Legal males	Females	Total
39-2	24	-[a]	-	-	-	-
39-4	18	-[a]	-	-	-	-
41-5	27	8	27	11	38	76
41.5-3	23	8	37	12	15	64
42-1	18	-[a]	-	-	-	-
42-6	27	8	20	13	14	47
43-3	18	8[b]	33	11	2	46
45-5	15	7[b]	38	9	6	53
44-6	21	8	34	19	7	60

[a]No traps set at these stations

[b]One trap torn

A certain degree of similarity in the size frequency distributions is expected, since the traps selectively sample the adult segment (100 mm) of the crab population. The wire mesh of the crab trap is large enough so that crabs smaller than 100 mm shoulder width can escape even when the escape ports are wired shut. Further, most of the legal male crabs available on the fishing grounds are harvested each year during the crab season (Jow, 1961). Thus it is expected that most crabs collected with these traps would be in this size range.

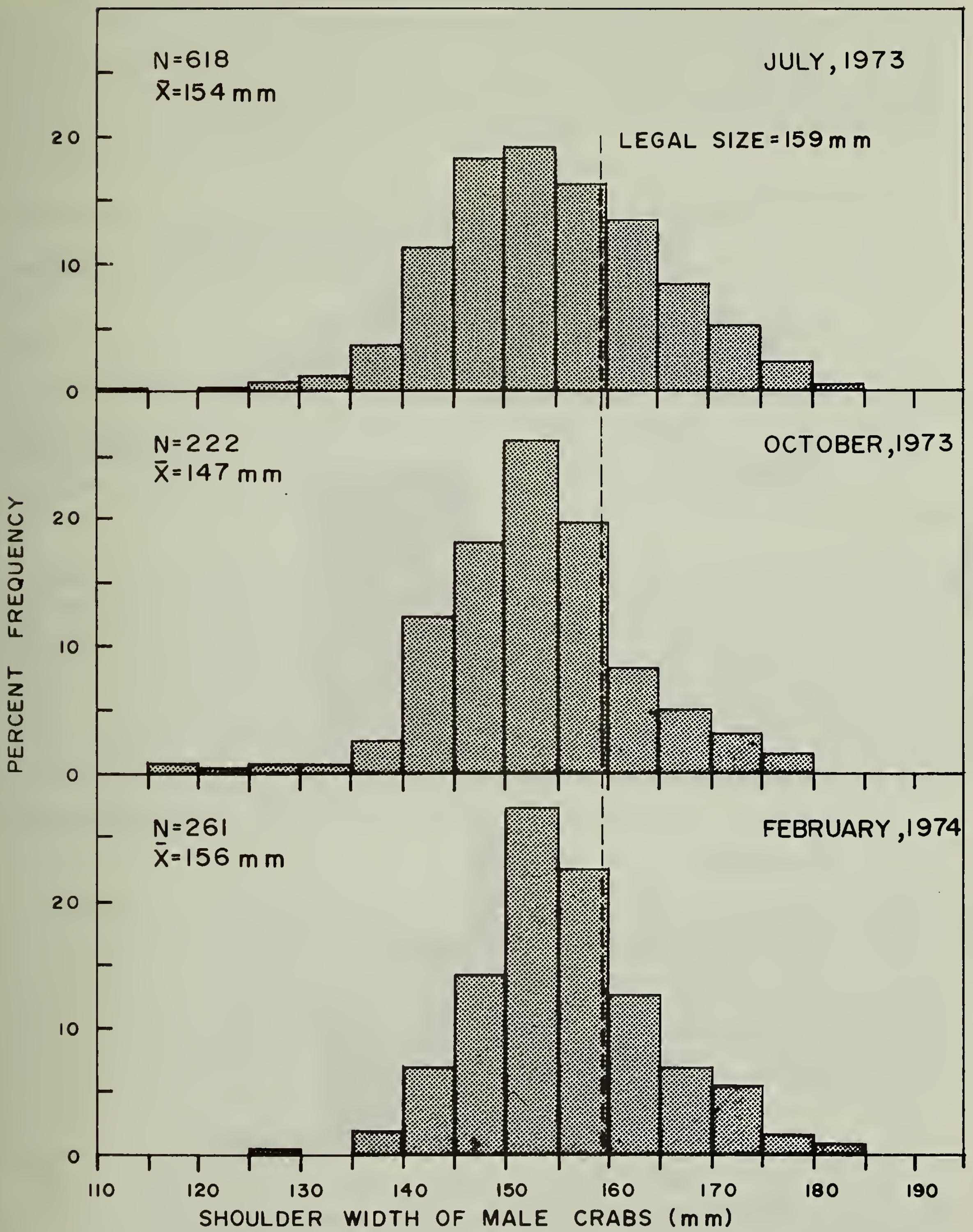


Fig. 4-7. Size Frequency Distribution of Trap-Caught Male Dungeness Crabs, Gulf of the Farallones

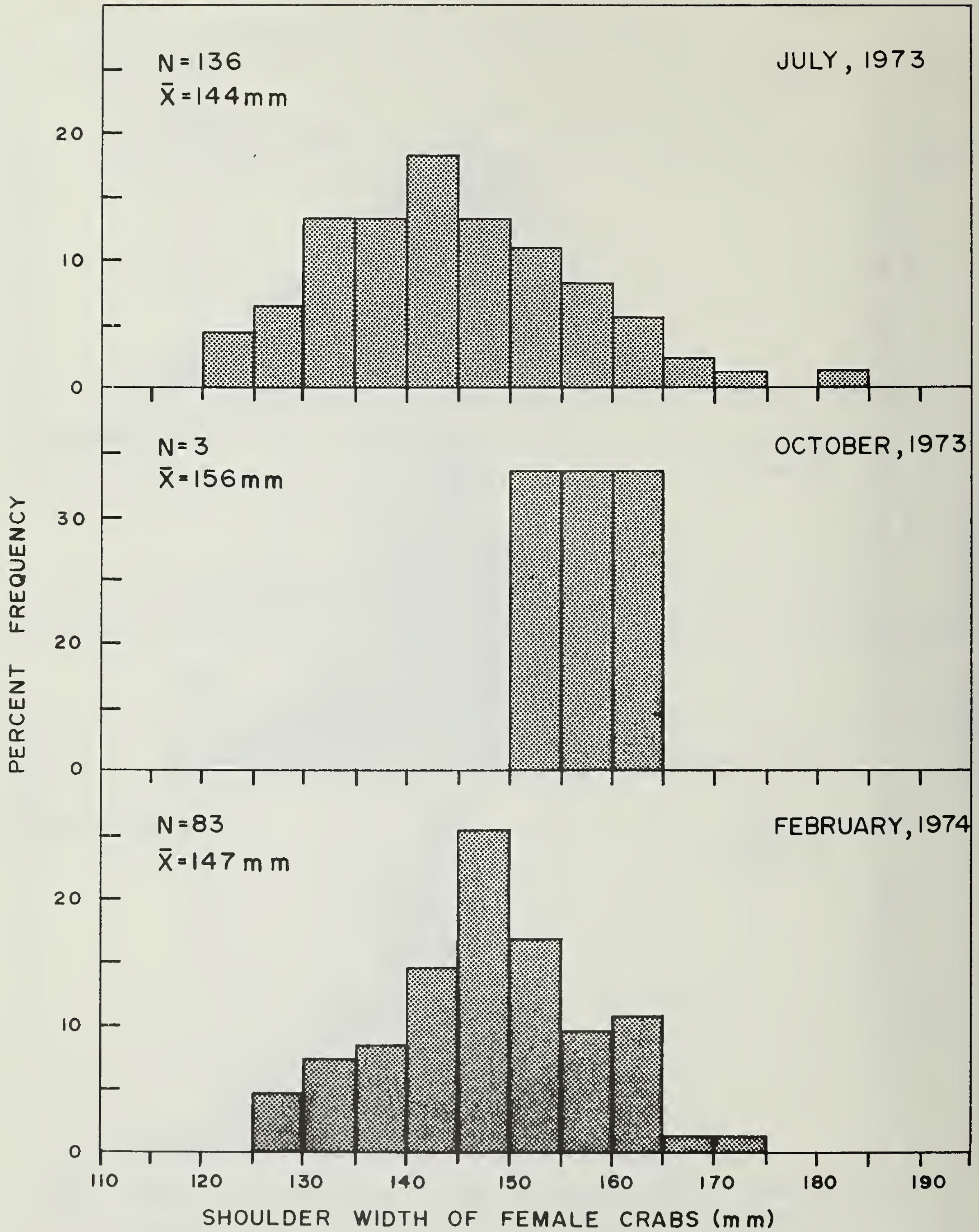


Fig. 4-8. Size Frequency Distribution of Trap-Caught Female Dungeness Crabs, Gulf of the Farallones

Shell Condition. Table 4-25 indicates the shell conditions of the male Dungeness crabs. Most of the crabs collected in the July 1973 catch had soft shells, indicating that they had only recently molted to adult size (100 mm). Normally mating takes place from March to July between hard-shelled male crabs and soft-shelled female crabs (Poole and Gotshall, 1965). Therefore, it is not surprising to find that only 67.9 percent of the hard-shelled adult males had mating marks on their chelipeds (claws).

Table 4-25. Shell Condition of Male Dungeness Crabs Collected in Crab Traps, Gulf of the Farallones

Survey	Condition			Mating marks	
	Hard	Filling	Soft	Hard	Filling
July, 1973	193	44	453	131	7
October, 1973	177	39	6	136	0
February, 1974	224	37	0	56	0

Most of the males in the October 1973 catch were hard-shelled and 76.8 percent bore mating marks. The paucity of soft-shelled and filling crabs suggests that most of the crabs that molted during the summer had hardened. The high percentage of mating marks indicates that most of these crabs had mated before July and had not yet molted or there was an extended mating season. Almost all the males in the February 1974 catch were hard-shelled and 25 percent had mating marks. The hard-shelled crabs without mating marks had either not as yet mated or had only recently molted to the adult size. Most males pass through at least one fishing season as hard-shelled sublegal crabs and are available for mating during the spring mating season (Poole and Gotshall, 1965).

Red Crabs

The only other species of crab collected in any number on the trapping surveys was the red crab, Cancer productus. This species is relatively common locally, but no estimates of population size are available. Red crabs yield less meat than do Dungeness crabs; thus they are rarely exploited commercially (Frey, 1971). Table 4-26 summarizes the red crab catch data for the three surveys. Most of the red crabs were collected in the October 1973 survey; males and females were collected on that survey in contrast to the Dungeness crabs. No interpretation of the data is made because of the lack of knowledge of the natural history of this species.

Fishes

Four species of fishes were collected on the trapping surveys. No more than two specimens of any of these species were found in any one trap. Even through these species were considered incidental in the trapping survey, their presence in the traps may be important from a conservation viewpoint. Commercial crab traps when lost may continue to fish as long as the wire mesh is intact because the trapped fishes and invertebrates serve as bait. The size ranges of these species are presented in Table 4-27.

Table 4-26. Catch data for the Red Crab, Cancer productus, Collected in Crab Traps, Gulf of the Farallones

Shoulder width mm	July 1973	October 1973	February 1974	Total
80-89	-	1	-	1
90-99	-	-	-	-
100-109	-	17	-	17
110-119	3	49	3	55
120-129	4	82	4	85
130-139	3	38	-	41
140-149	1	13	-	14
150-159	2	9	2	13
160-169	-	4	-	1
Total	13	213	9	235
Mean size, mm	131	125	127	125
Sex ratio (M:F)	1:1.6	1:2.5	1:2	1:2.4

Table 4-27. Size Range (Standard Length in mm) of Fishes Collected in Crab Traps, Gulf of the Farallones

Species	July 1973	October 1973	February 1974
Pacific sanddab	191-305	212-241	-
English sole	320	-	-
Sand sole	-	264	-
Brown rockfish	331-430	238-297	238-325

ANALYSIS OF THE BENTHIC INFAUNA SAMPLES

Data on benthic infauna obtained from the benthic grab sampling surveys are discussed below with respect to the general composition of the catches, and the major components of the invertebrate fauna.

General Composition of the Catches

The three surveys of the benthic invertebrates demonstrated that the sediments in the vicinity of the proposed wastewater discharge support a rich and diverse fauna. Approximately 150 species representing 11 phyla were collected. Table 4-28 summarizes the major constituents of the collection; a complete taxonomic list and a tabulation by survey of all organisms collected are appended.

A total of 16,287 organisms were identified and enumerated. Of these, 8,482 were polychaete worms. Also abundant were gastropod and pelecypod mollusks, which totaled 4,123, and various crustaceans, which totaled 3,198. Figure 4-9 shows the total number of animals collected at each station plotted as isopleths on the sampling grid for the July 1973, October 1973 and February 1974 surveys, respectively. As can be seen in Fig. 4-9, in all surveys the greatest number of

invertebrate organisms were collected at Station 41.5-3 and the fewest animals were collected at the stations in the north and northeastern sections of the grid which were located on the bar.

Table 4-28. Abundance and Percent Composition of Major Taxonomic Components of the Benthic Infauna Collected in Grab Samples, Gulf of the Farallones

Taxon	Abundance				Percent composition			
	July 1973	October 1973	February 1974	Total	July 1973	October 1973	February 1974	Total
Polychaetes	3,116	4,134	1,232	8,482	70.4	47.0	40.3	52.1
Mollusks	243	2,785	1,133	4,161	5.5	31.6	37.0	25.5
Crustaceans	970	1,691	537	3,198	21.9	19.2	17.5	19.6
Echinoderms	25	104	115	244	0.6	1.2	3.8	1.5
Others [a]	69	90	43	202	1.6	1.0	1.4	1.2
Total	4,423	8,804	3,060	16,287	100.0	100.0	100.0	99.9

[a] Includes turbellarians, nemerteans and hemichordates. Foraminifers, coelenterates and nematodes were also found, but were not enumerated.

A relationship exists between the number of animals found at a particular station and the silt-clay fraction at that station. The stations with the fewest animals generally were those with the highest percentage of sand in the sediments. These were stations closest to or on the San Francisco Bar. The habitat at the bar stations is apparently not suitable for most species. This is likely because the bar is an area of considerable turbulence and the sediments are probably not stable. At Station 41.5-3, the highest silt-clay fraction was measured, and a high number of animals was found. Apparently the finer sediments provided a more suitable habitat.

Major Components of the Benthic Invertebrate Fauna

This section discusses the major taxonomic groups represented in the benthic invertebrate fauna. Some natural history notes for the major component species are included. Unless otherwise designated, references for the natural history notes are Barnes (1974), Light (1954), and Ricketts and Calvin (1968).

Polychaete Worms. Polychaete worms, a class in the Phylum Annelida, are a major component of most marine benthic communities, especially in near shore areas. Most species are only a few millimeters in length, but they often aggregate in extensive colonies. Very little is known of the natural history of most polychaete species, particularly those inhabiting subtidal areas where they cannot be readily observed. Polychaete worms can be divided taxonomically into two major groups, the Errantia or free-living worms and the Sedentaria or tube dwellers. This division indicates the habits of the worms, but there is considerable overlap. Many errant worms, for example, are tube dwellers and, conversely, many sedentary worms crawl out of their tubes. Polychaete worms form an integral part of the food chain. Errant polychaetes usually are either predaceous, eating small invertebrates and other living material, or omnivorous, eating detritus material in addition to living matter; sedentary worms are mostly detritus or filter feeders. Polychaetes are eaten by a variety of larger invertebrates and bottom-dwelling fishes.

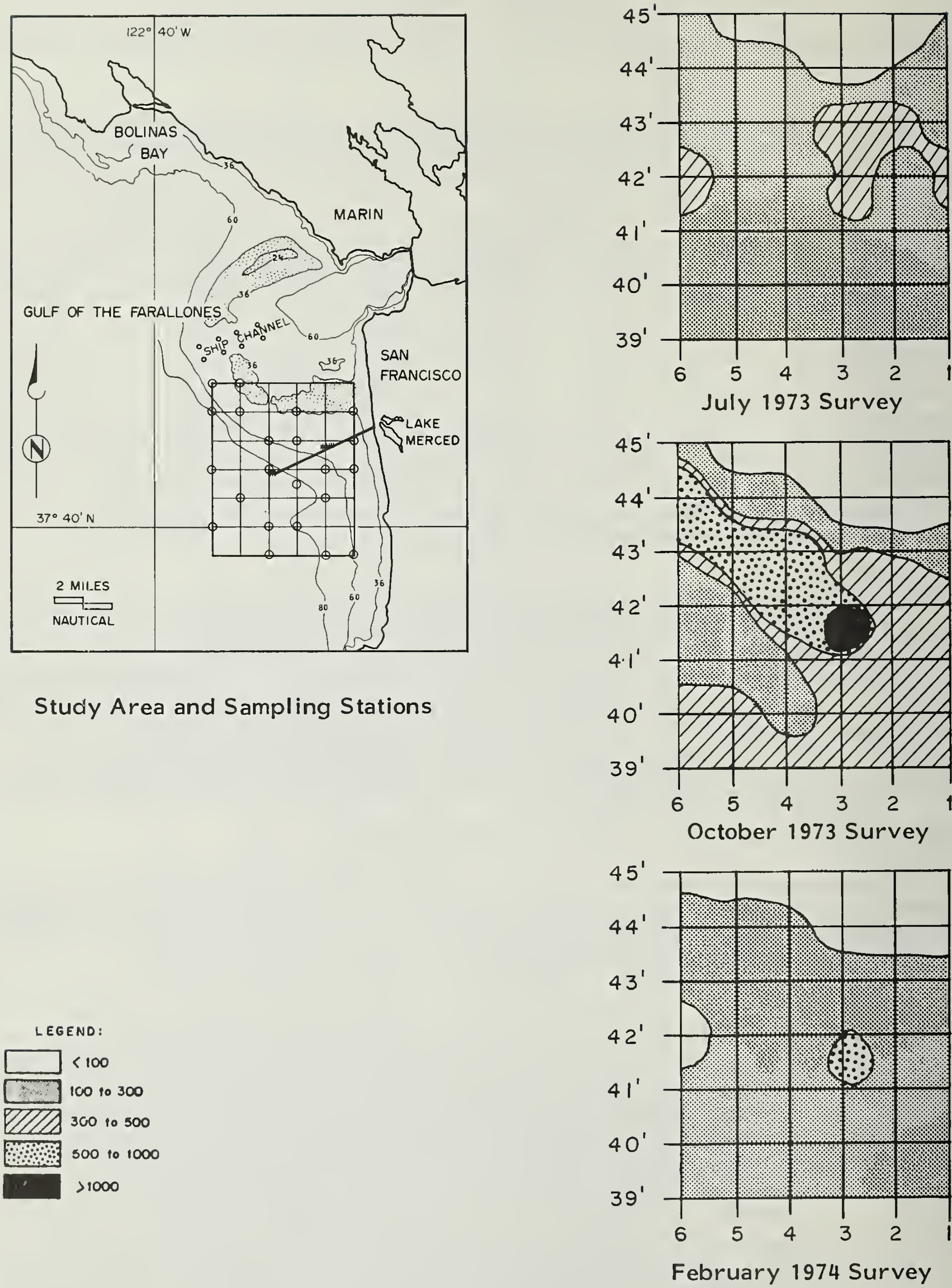


Fig. 4-9. Areal Density of Benthic Invertebrate Fauna in the Study Area, Gulf of the Farallones

Polychaete worms were the numerically dominant group of animals observed in this study. Overall, they composed over 50 percent of the animals identified, and were found at all 22 stations, although in widely varying numbers. Both errant and sedentary families were well represented so that a broad cross section of feeding types were included. The greatest concentrations of polychaete worms occurred in the mid-section of the study area, generally at stations with a high silt-clay fraction in the sediments, such as Station 41.5-3 (Fig. 4-10). There was a positive correlation between the numbers of polychaete worms and the silt-clay fraction. This correlation was statistically significant at the 95 percent level when analyzed by a correlation analysis using data from the October 1973 and February 1974 surveys ($r = 0.78$ with 18 degrees of freedom in October 1973 and $r = 0.44$ with 20 degrees of freedom in February 1974). Although no data on sediment composition was obtained on the July 1973 survey, it is important to note that a comparison between the polychaete worm data from the survey and the percentages of silt-clay from either the October 1973 or February 1974 surveys would not result in a significant positive correlation. Whether the deviation of the July 1973 worm data from the distribution pattern found on the other surveys was caused by a seasonal shift in the bottom sediments or was caused by some other factor could not be determined. Some substantial deviations from the trend also occurred on the October 1973 and February 1974 surveys, especially at stations 42-1 and 43-3. These stations are located near the edge of the sand bar so that the difference in the location where the samples for biological and particle size analyses were collected was important.

Table 4-29 indicates the species of polychaete worms, numbers of specimens collected in the three surveys, and numbers of stations at which specimens were found. Species composing less than one percent of the polychaete worms collected are not listed. The species are ranked according to their overall numerical abundance.

Nephtys cornuta franciscana, an errant polychaete of the family Nephtyidae, was the most common species overall. Most specimens were collected on the October 1973 survey; very few were found in the February 1974 survey. Since the species was absent entirely from most of the 66 samples taken on the latter survey, it appears that this reflects an actual population decline. Whether or not fluctuations of this type are normal could not be ascertained. Although most species were less abundant on the February 1974 survey, relative declines were not nearly as sharp. A related species, Nephtys caecoides was the fourth most abundant polychaete worm; it too was found in fewer numbers in February 1974. Even when relatively abundant, Nephtys cornuta franciscana occurred at only 19 stations on the October 1973 survey. It was most common at stations 41.5-3, 42-1, 42-4, and 44-6 where 278, 126, 91, 108, and 191 worms were found, respectively. It was found in appreciable numbers in each sample. This shows that the species occurs in relatively large numbers over a wide area, since the samples from each station were collected several hundred meters apart. The species was least abundant on all surveys at the stations nearest the bar. Perhaps this reflects their food preferences because Nephtys is believed to be primarily predaceous (Clarke, 1962). Nephtys caecoides, however, was present at the stations in the vicinity of the bar in roughly the same proportions as at other stations.

The second most abundant species was Glycinde polygnatha a carnivorous, errant species in the family Goniadidae. It was relatively abundant in July 1973, but was not found in appreciable numbers on subsequent surveys. Although it was found at 21 stations, the largest numbers were collected in the middle part of the study area and the smallest numbers at stations on the bar.

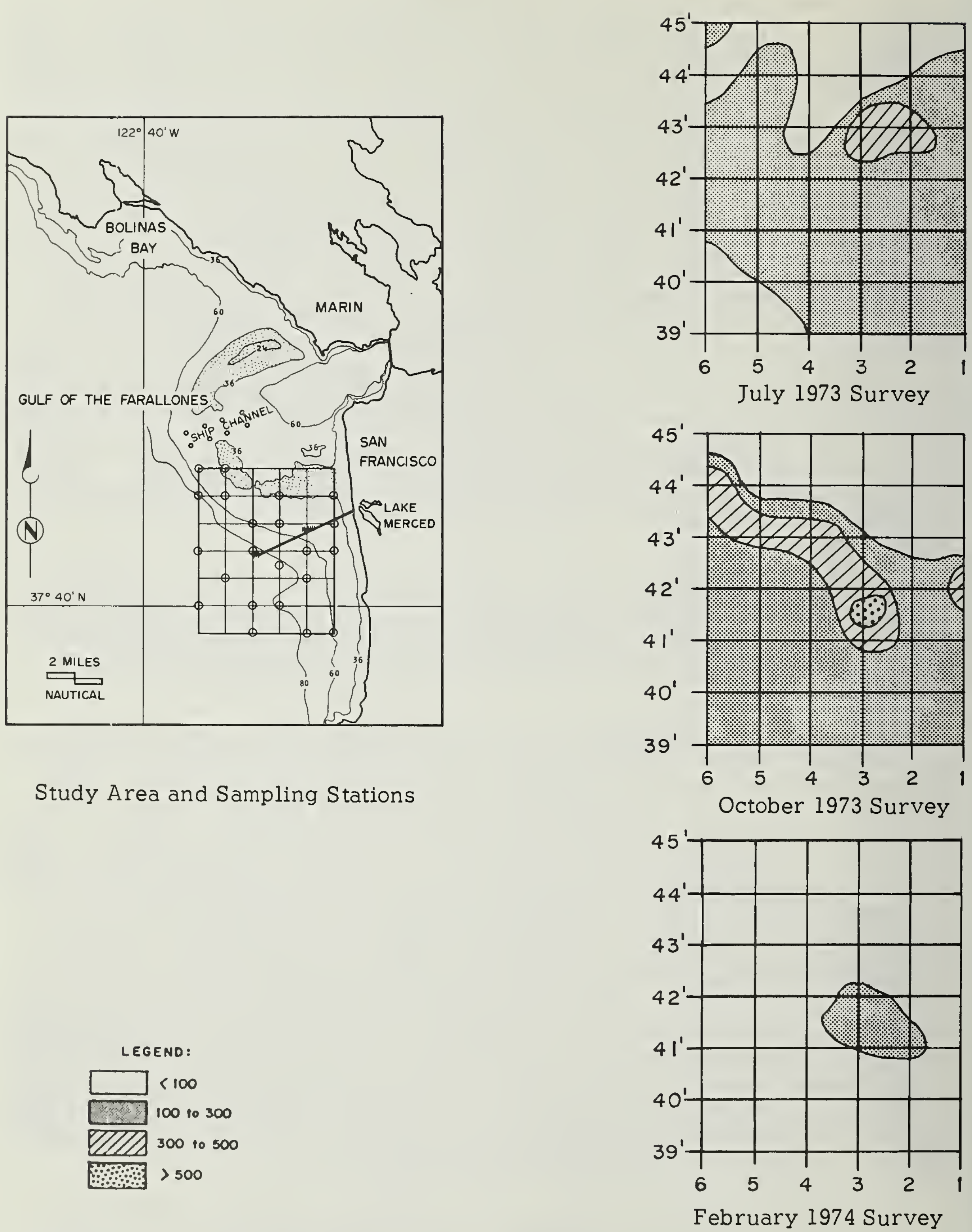


Fig. 4-10. Areal Density of Polychaete Worms in the Study Area, Gulf of the Farallones

Table 4-29. Most Common Species of Polychaete Worms, Gulf of the Farallones

Species	Abundance				Number of Stations Found			
	July 1973	October 1973	February 1974	Total	July 1973	October 1973	February 1974	Total
Nephtys cornuta franciscana	192	1,149	28	1,369	16	19	9	22
Glycinde polygnatha	732	337	124	1,193	20	21	21	21
Spiophanes bombyx	576	192	263	1,031	18	20	18	22
Nephtys caecoides	461	326	109	896	22	22	22	22
Prionospio pygmaeus	91	603	131	825	18	20	18	21
Capitita ambiseta	273	244	127	644	18	11	14	20
Nothria elegans	237	163	86	486	15	18	17	20
Pectinaria californiensis	0	131	1	132	0	10	1	10
Armandia brevis	11	110	2	123	2	13	2	14
Magelona sacculata	43	50	17	110	16	16	11	20
Amaeana occidentalis	2	41	62	105	2	10	13	16
Magelona pitelkai	19	52	26	97	6	15	11	17
Owenia collaris	26	55	14	95	6	9	4	11

Spiophanes bombyx and *Prionospio pygmaeus*, the third and fifth most common species collected, respectively, are both sedentary polychaetes of the family Spionidae. Both species were fairly ubiquitous in the study area. *Spiophanes bombyx* was found at all 22 stations and *Prionospio pygmaeus* at 21 stations. Although the two species occurred together at most stations, they were usually not found in the same sample in large numbers. *Spiophanes bombyx* was most abundant in the summer and least abundant in the fall, whereas *Prionospio pygmaeus* was least abundant in the summer and most abundant in the fall. Whether or not this pattern is of consequence is not known. Both species are tube dwellers and are detritus feeders.

Capitita ambiseta was the sixth most common species collected. It is also a tube building worm and belongs to the family Capitellidae. This species was slightly more abundant in the summer and fall than in the winter. The largest concentrations were at Station 41.5-3 with substantial numbers also found at the stations immediately adjacent. This species may be of some importance as an indicator species for future

monitoring if an outfall is located in the study area. Capitellid polychaetes have been used as indicator species in other areas, notably southern California. The SCCWRP report (1973) categorizes a relative, Capitella capitata as being tolerant of outfall areas or inhabiting areas of fine sediment. Capitita ambiseta, on the other hand, was listed with a group of species that avoid outfall areas. The report also states that Capitita ambiseta is a very small worm and superficially resembles juveniles of a related species, Mediomastus californiensis. Such extreme care must be taken to ensure that correct identifications are made that the utility of the species for routing monitoring is questionable.

The six species discussed represent approximately 70 percent of the polychaete worms collected. The remaining species were collected in too few numbers to justify discussing their distribution patterns. Generally the most species and the largest numbers of worms were found at stations near the center of the grid and the fewest at stations in the northern part of the grid near the bar. Approximately 35 to 40 different species occurred at Station 41.5-3, for example, as opposed to less than ten species at Station 45-5. Very little is known about the natural history of most of the species. One exception is Pectinaria californiensis, which has been studied extensively in the Puget Sound area (Nichols, 1970).

Mollusks. Three classes of the Phylum Molluska were represented in the collection. These are the Pelecypoda, the Gastropoda, and the Scaphopoda. The pelecypods comprise the clams, oysters, and mussels. These animals inhabit a variety of sand and mud habitats and are usually a major component of the benthic fauna. In addition, many species live on or in harder substrates such as rocks and wood pilings, so that they are also well represented in intertidal surveys. Most pelecypods are filter feeders. They screen out bits of organic matter from the water while remaining partially submerged in the substrate. Pelecypods are preyed upon by fishes and other invertebrates, especially the gastropods. The gastropods are a large and diverse class which includes the marine snails; the group, however, was not well represented in the study area. Most of the species found on the surveys are carnivorous types that prey on pelecypods. The scaphopods are a relatively small group of burrowing animals. They are shaped like a tusk and are commonly known as tusk shells. These animals remain buried in the substrate, preferring sand, and feed on microscopic organisms in the water. Although a small group with respect to numbers of species, these animals may be locally abundant.

The pelecypods were the most numerous group, accounting for 3,804 of the 4,161 mollusks found. Of these, the most common family was the Tellinidae which includes the genera Macoma and Tellina. Most of the specimens of Tellina were juvenile forms which were not much larger than coarse sand grains. Although their small size made identification difficult, most were identified as Tellina modesta. This species was very abundant at some stations, especially in October 1973. At Station 43-4, for example, 318 specimens were found. They were also numerous at stations 41.5-3 and 44-6 with respective counts of 228 and 179 on the fall survey. Specimens of Mysella, a genus in the Family Montocutidae, was also commonly collected. Altogether 888 specimens of this genus were found, but they were not identified to species because of their small size. Mysella was most common in the fall with the greatest concentration being found at Station 41.5-3.

Only 319 gastropods were collected during the entire study, and most of these were found on the fall and winter surveys. None of the species was common enough to establish its distribution. The relatively few specimens found were widely distributed among the stations with no notable concentrations. Some of the species

collected are common intertidal inhabitants. Among these are Nassarius perpinguis, Olivella biplicata, and Olivella pycna. Polinices are relatively large snails which at maturity measure several centimeters across. Polinices snails are predaceous and feed mainly on pelecypods.

Cadalus and Dentalium were the two scaphopod genera identified. A total of 38 specimens were collected and these were distributed throughout the study area. The only concentration was 14 specimens at Station 41.5-3 on the February 1974 survey.

Crustacea. The class Crustacea is a large and diverse group that belongs in the phylum Arthropoda. Among the crustacea are such common forms as crabs and shrimp. The major groups represented in the collections are listed in Table 4-30. The subclass Malacostraca, which includes among others the orders Mysidacea, Cumacea, Isopoda, Amphipoda, and Decapoda, accounted for approximately 84 percent of the crustaceans found. Most of the remainder were ostracods. Generally the greatest concentrations of these organisms were at the stations in the middle and southern sections of the grid. Few crustaceans occurred at stations on the bar. No ostracods or isopods, for example, were found at stations 44-3 and 45-5. The forms and habits of these groups are too diverse for any general discussion of crustaceans, therefore each group is briefly characterized in the following paragraphs with a discussion of respective representatives.

Table 4-30. Data for the Major Groups of Crustaceans Collected in Grab Samples, Gulf of the Farallones

Taxonomic group	No. of individuals	No. of stations	No. of species
Subclass Ostracoda	518	20	4
Subclass Cirripedia	1	1	1
Subclass Malacostraca			
Order Mysidacea	1	1	1
Order Cumacea	474	21	2
Order Isopoda	169	20	8
Order Amphipoda	1735	22	26
Order Decapoda	27	12	5

The ostracods or seed shrimp are small animals, generally not more than two to three millimeters in length, and are enclosed in a bivalve carapace resembling that of the pelecypods. Most of these animals inhabit the upper sediment layers and feed by filtering minute particles from the water. A few species are scavengers, feeding on detritus particles, and a few are predaceous or parasitic. *Euphilomedes carcharodonta* was the most common ostracod species found on the surveys. A total of 336 specimens were identified as to species. An additional 170 identified only as *Euphilomedes* sp. probably belonged to this species also. Most of the specimens were collected in October 1973 and were found at 19 stations on that survey. They were present in greater numbers at stations in the southern part of the grid, farthest from the bar, with densities estimated at several hundred per square meter not uncommon. Other isopods included the related species *Euphilomedes oblonga*, *Cylindroleberis mariae*, and *Cytherella* sp., but none of these was collected in more than a few samples.

Cumaceans are shrimp-like animals that live buried in the upper sediments. Most of these animals, including *Diastylopsis*, are filter feeders. *Diastylopsis* was found in most samples on the July and October surveys, but was uncommon in the February 1974 samples. At several stations these animals were very numerous. One sample collected at Station 42-2 in July 1973 contained 41 specimens, indicating a density in excess of 1,000 per square meter. *Diastylopsis* was found at all stations except 44-3 and is apparently indifferent to the composition of the sediments. *Hemilamprops californica* is another cumacean collected on the surveys, but never more than one or two specimens were found in any sample. This species also buries itself in the upper sediments and probably feeds by scraping organic material from sand grains. Mysidaceans are another group of shrimp-like animals and are similar in size to the cumaceans. Only one mysidacean was found; this specimen was not identified as to species. Although rare in this study, mysidaceans can occur in large numbers. Generally, however, they would be expected to be found in shallower waters among seaweeds and grasses in intertidal areas.

At least seven species of isopods were found at various stations throughout the study area. These animals constituted only a small fraction of the total number of crustaceans found in this study and, therefore, are not discussed individually. Isopods can be generally characterized as being dorsoventrally flattened animals. They are mostly scavengers that burrow in the sediments in search of food, although some are parasites on fish.

The amphipods, in contrast to the isopods, are laterally flattened animals. Amphipods have a diversity of habits although the species found in the collections are primarily burrowers. Most species are scavengers, but some such as *Corophium* are filter feeders. The most common species found in this study was *Paraphoxus fatigans*, a scavenger; a total of 1,088 specimens was collected. It was found at all but one station, and was most common at stations south of the bar. It apparently prefers finer sediments. The greatest concentrations were at Station 41.5-3 and adjacent stations, particularly in the February 1974 survey. Five other species in the genus *Paraphoxus* were also identified, but these were found in much fewer numbers than *Paraphoxus fatigans*. Other amphipod species commonly found in the collections were *Eohaustorius sencillus*, *Monoculodes spinipes*, *Photis conchicola*, and *Synchelidium* sp. None of these species were found in abundance, but all were well distributed among the stations, even near the bar.

The decapods include crabs and shrimp, and are the largest group of crustaceans with respect to numbers of species. A total of 27 specimens was collected in the benthic grab samples. Two shrimp species were found, Crago alaskensis elongata, and Crago stylirostris at stations 42-6 and 45-5, respectively. A few hermit crabs were found at bar stations and at stations farther south. One juvenile Cancer magister crab was found at Station 45-5, and the pea crab, Pinnixa was found at stations 39-1 and 42-1. Most of these species are scavengers, but are also predaceous if the opportunity arises. The Crago shrimp and Cancer magister often burrow in the sand and feed on detritus as well as live prey. Hermit crabs are scavengers and inhabit gastropod shells. Pea crabs often inhabit tubes of polychaete worms and are primarily filter feeders.

Echinoderms. Echinoderms are common marine organisms and include such forms as sand dollars, sea urchins, and starfish although none of the latter were collected in the grab samples. Tiny ophiuroids or brittle stars were found at many stations on each survey. These animals measured only a few millimeters in diameter. Most have five radial arms as do some starfish, but are much smaller and more delicate in appearance. They live in sandy sediments and feed on detrital material.

The specimens of the sand dollar, Dendraster excentricus collected were mostly juveniles, measuring only a few millimeters in diameter; whereas the mature specimens measured several centimeters across. Because of their relatively large size, few mature specimens were captured. Dendraster excentricus was found at several stations, but was not common at Station 44-3. Reference is made to the trawl collections made in conjunction with the benthic invertebrate grabs, since large quantities were collected at this and only this station. Sand dollars lie buried in sandy substrates and feed on minute organic particles. No explanation is offered for their apparent preference for Station 44-3. It is noted, however, that there was a very small silt-clay fraction at that station. Also, this station was marked by the absence or infrequent occurrence of most other species.

Miscellaneous Groups. Several other groups of organisms were present in the sediments in addition to the polychaetes, mollusks, crustacea, and echinoderms. None of these groups was particularly numerous, but they are important constituents of the benthic community and their overall presence is indicative of the great diversity of species in the study area. The mesh of the screen used to sift the sediment samples was so fine that some animals were retained which would not normally be included with the macroinvertebrates. Among these were the nonionid foraminifers and the nematodes. Both these groups are generally present in the marine sediments in large numbers. Other groups with occasional representatives in the collections were the hydrozoan coelenterates, turbellarians (flat worms), phoronids, echiuroids, and hemichordates.

CHAPTER 5

BENTHIC MARINE RESOURCES AT A PROPOSED BAY DISPOSAL SITE

Qualitative surveys were made in the vicinity of the present Southeast WPCP outfall at Islais Creek, south San Francisco Bay, to obtain information on the kinds of organisms which could be found. The proposed bay disposal site, unlike the proposed ocean site, has been monitored continuously since 1972 by the City and County of San Francisco as part of their Self-Monitoring Program for reporting to the Regional Water Quality Control Board. A second part of this study was a review of the literature to collate data that is available on many of the species inhabiting the Islais Creek area (e.g., Herald and Simpson, 1955, Aplin, 1967; Moriguchi, 1973; Pacific Gas and Electric Company, 1973; Stanford Research Institute, 1973; and Herald and Innes, manuscript, 1965).

MATERIALS AND METHODS

The sampling stations, sampling equipment and procedures, and sample processing procedures are described below.

Sampling Stations

The study area in the vicinity of the present Southeast WPCP outfall site at Islais Creek (37° 45.0' N Latitude, 122° 22.2' W Longitude) is shown on the map in Fig. 5-1. Seven of these stations had been selected by the San Francisco Bay Regional Water Quality Control Board (RWQCB) to sample for physical, chemical and biological analyses for the Self-Monitoring Program. Five additional sampling stations were established for this study to provide additional background information in areas where a new submarine diffuser could be located (see Chapter 7 for descriptions of alternative discharge locations). Trawling surveys were also made in the same study area. The approximate areas in which each of the trawls was made are shown in Fig. 5-2.

Survey Dates

Some of the data reported in this chapter are from surveys performed over a three year period, 1972 through 1974. Samples for physical, chemical and biological analyses have been collected from seven stations on a quarterly basis since the first quarter of 1972 as part of the Self-Monitoring Program. Samples for chemical and biological analyses were collected from the five new stations on a quarterly basis from the second quarter of 1973 through the second quarter of 1974. During this period, all twelve stations were sampled concurrently. Trawling surveys were made on four dates: December 3, 1973; March 18, 1974; May 30, 1974; and October 22, 1974.

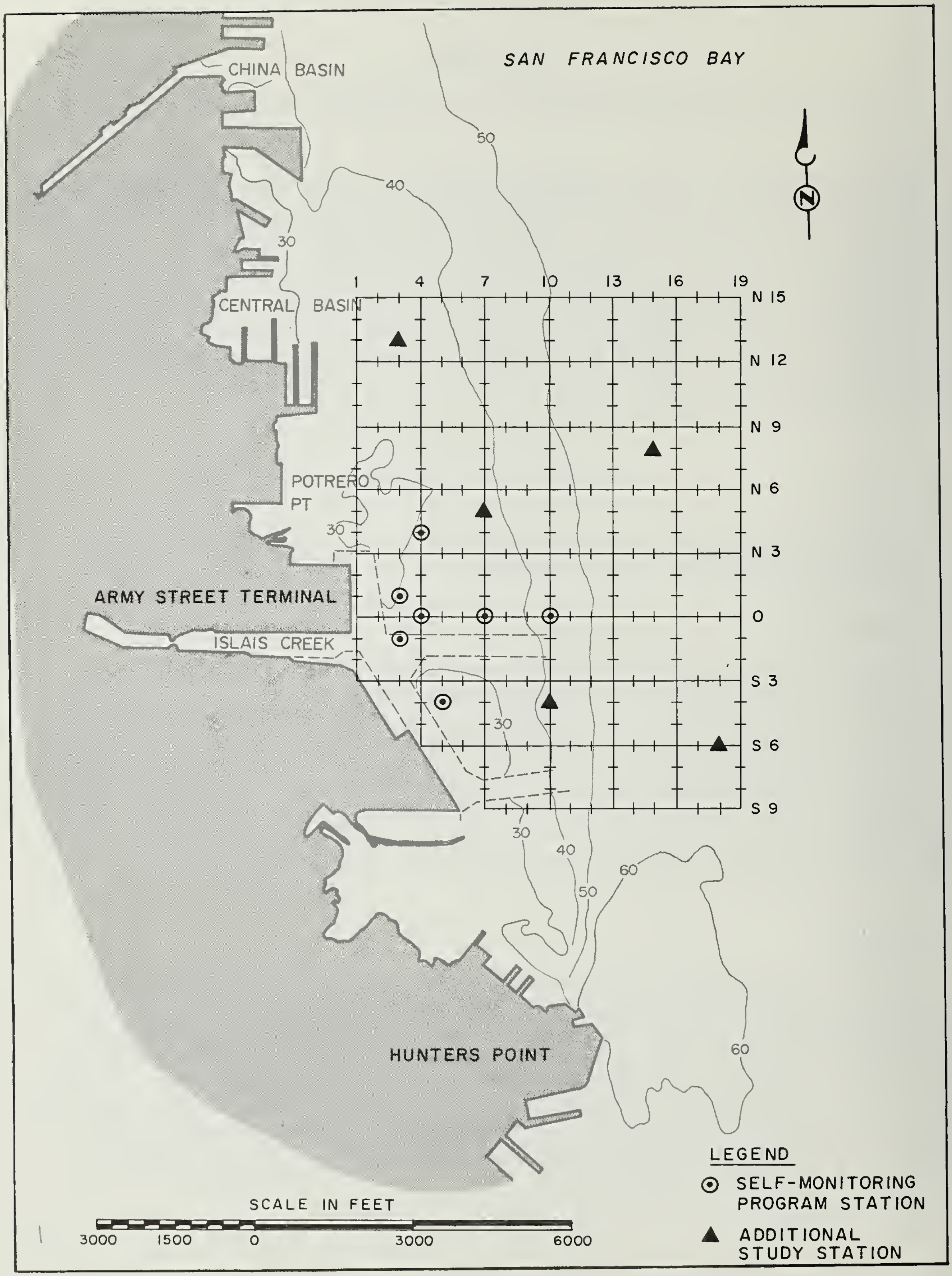


Fig. 5-1. Map of Study Area Showing Sediment Sampling Stations in the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay

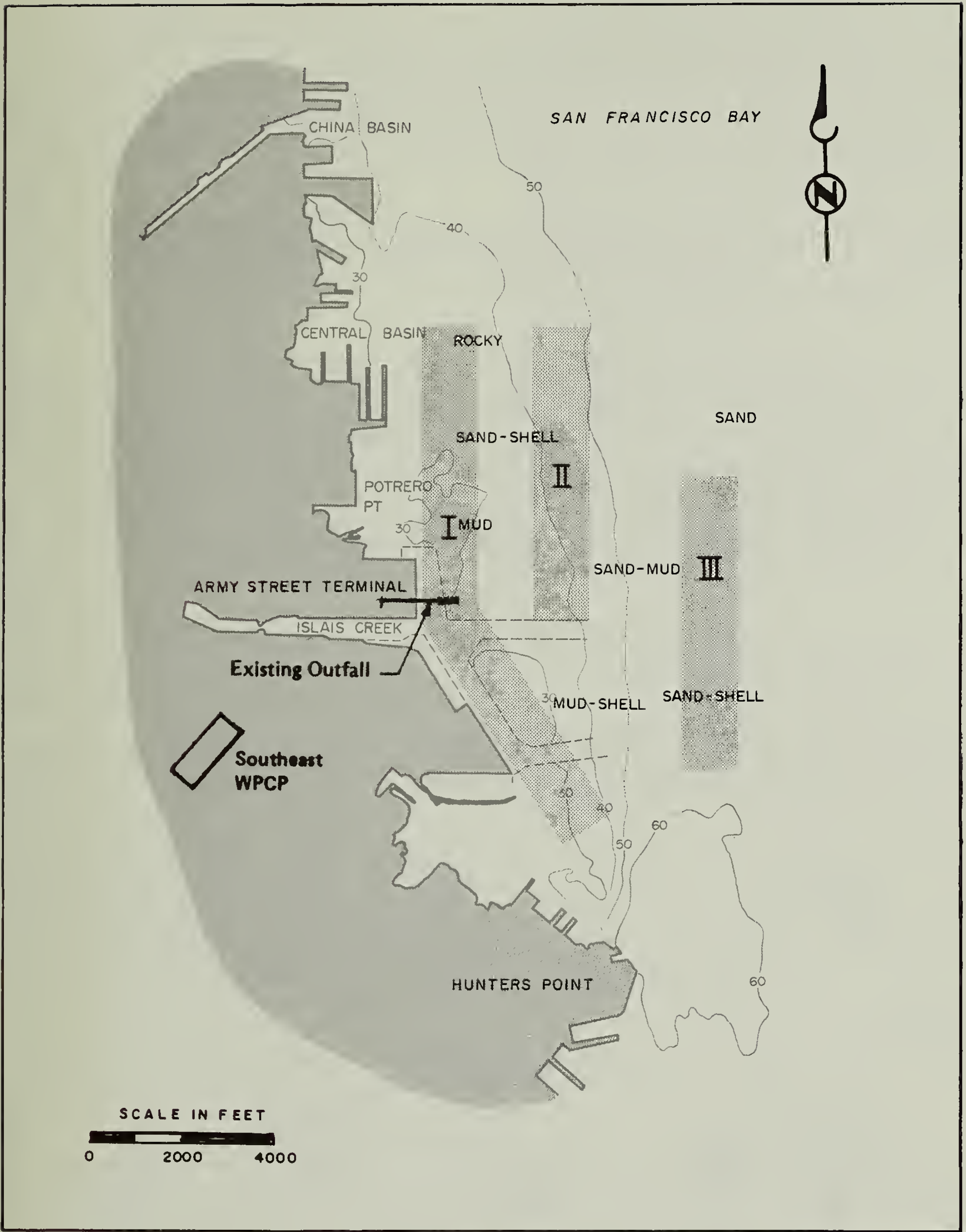


Fig. 5-2. Map Showing Trawl Sampling Areas in the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay

Sampling Equipment and Procedures

The sampling equipment and the procedures used for collecting the sediment samples and making the bottom trawls are described below. The procedures used for collecting the sediment samples were those recommended by the RWQCB for the Self-Monitoring Program. Since data had been collected for over a year before the initiation of these field surveys, those procedures were retained so the data would be comparable.

Sediment and Benthic Infauna Samples. Two grab samples were collected and combined in a composite sample at each station for analyses of sediments and benthic organisms. Sampling was conducted from Environmental Quality Analysts' 25-foot vessel, the Camanche.

All samples from the first quarter of 1972 to the second quarter of 1974 were collected with a Peterson dredge (Fig. 5-3). This dredge samples a surface area of 0.12 square meters; thus a total area of 0.24 square meters was represented by the composite sample from each station. Also, five composite samples of two grabs each were made at three stations to obtain information on the variability inherent in the sampling procedure. The volumes of the composite samples were approximated. Care was taken to ensure that samples were collected with the sediment surface still intact, so that a relatively constant surface area was sampled even though the sample volumes varied somewhat.

The sampling was scheduled to be completed with the data from the second quarter of 1974. However, it was subsequently decided that the additional data from the third and fourth quarters of 1974, collected for the Self-Monitoring Program, would also be used. A Ponar dredge which samples a 0.052 square meter surface area was substituted for the Peterson dredge in the third and fourth quarters of 1974 (Fig. 5-4). This change in sampling equipment affected the number of organisms collected per unit area, since shallower samples were collected.

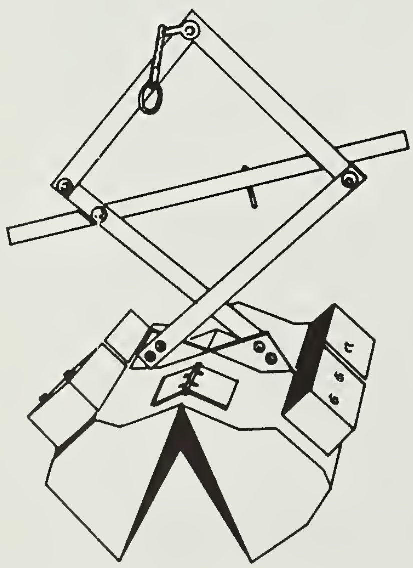


Fig. 5-3. Peterson Dredge Sampler

Bottom Trawls. Bottom trawls were made with a 24-foot otter board trawl net (Fig. 5-5). The body of the net was constructed of $1\frac{1}{2}$-inch bar mesh with a $\frac{1}{2}$-inch liner in the cod end. The foot of the net was weighted with 32 feet of 2/0 chain; no tickler chain was used. A pair of 16- by 30-inch wood doors with metal skids was attached directly to the net. Tow-warps consisted of two 75-foot lengths of $\frac{1}{2}$-inch nylon rope. The net was towed with a six to one scope (ratio of the length of the tow line to the station depth). A 100-foot safety rope with a float was attached to the cod end to dislodge the net in case it became snagged. The boat used for trawling was a 21-foot Boston Whaler.

The decision on the number of trawls made and areas sampled was dependent on the length of time it took to complete a minimum of three trawls and the presence

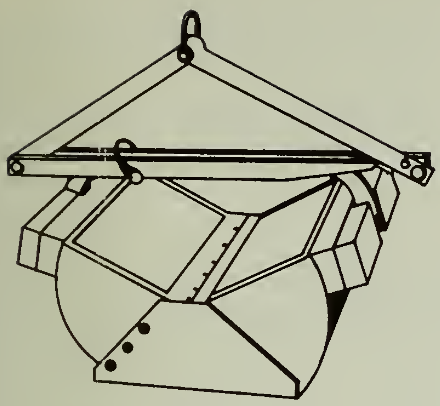


Fig. 5-4. Ponar Dredge Sampler

or absence of snags (Table 5-1). An attempt was made to sample at least three areas (Fig. 5-2). Area I was selected because it included three habitat types: a rocky shoal; a mud shoal; and a portion of the dredged channel. This area was about 30 feet deep. Area II had a mud-shell substrate and was about 40 feet deep. Area III had a sand-shell substrate and was approximately 60 feet deep.

Trawls were generally made in the direction of the current at about 1-2 knots. The length of time for the trawls varied between 10 and 30 minutes. Because this study was a qualitative rather than a quantitative study, variation in trawl time was not a controlling factor. Shorter trawls (10 minutes) were made in the inshore areas because of the increased possibility of snagging the net. Longer trawls of up to 30 minutes were made in deeper waters offshore where the bottom was less cluttered with debris.

Sample Processing Procedures

The procedures used for processing the sediment and trawl catch samples are described below.

Sediment and Benthic Infaunal Samples. Each composite sediment sample was mixed, and a subsample was then removed for chemical analysis. The remainder was sieved through a U.S. No. 35 mesh screen (0.5 mm opening) and the organisms were preserved in 10 percent formalin. A subsample ranging from 10 to 50 percent of the total number of organisms was removed for analysis and processed in the same manner as described in Chapter 4. The benthic organisms in all samples were identified as to species insofar as practicable using published keys (see appendix for list of keys). Enumerations were made of each taxon and the density was expressed as the number of organisms per square meter.

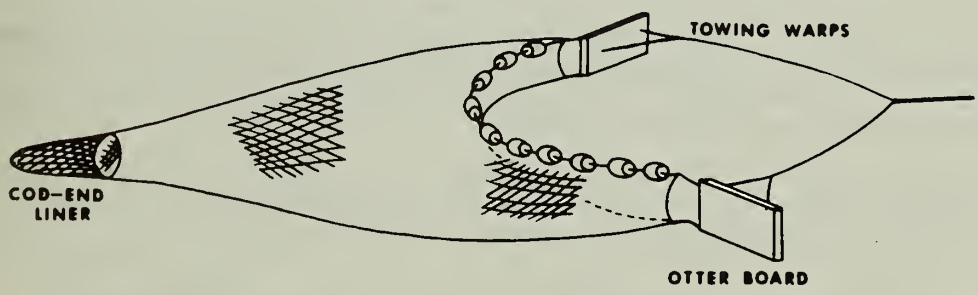


Fig. 5-5. Otter-Board Trawl Net

Table 5-1. Number and Duration of Tows Made During the Trawl Survey in the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay, 1974

Survey	Trawl area		
	I	II	III
December 3, 1973	2[a]	1[a]	1[a]
March 18, 1974	2[a]	2[a]	2[a]
May 30, 1974	2[a,b]	2[a,b]	1[b]
October 22, 1974	1[b]	4[b,c,d]	-

[a]10 minute trawl
[b]15 minute trawl
[c]20 minute trawl
[d]30 minute trawl

Sediment samples collected from the seven Self-Monitoring stations were analyzed for pH, oil and grease, percent hydrocarbons, chromium, copper, lead, zinc, and total sulfides in accordance with the requirements of the RWQCB. Analyses for cadmium, copper, chromium, mercury, nickel, lead, zinc and chlorinated hydrocarbons were made of samples collected at all twelve stations in February 1974. The analytical procedures used were in accordance with Standard Methods, 13th ed. (1971) and the U.S. Environmental Protection Agency (1969) (see appendix for details). Chemical analyses were performed by Environmental Quality Analysts, Inc. (EQA) through the second quarter of 1974 and by the City and County of San Francisco thereafter.

Trawl Catches. All organisms in each trawl haul were retained for examination. The catch was refrigerated immediately upon arrival at the laboratory, except for the October 22, 1974 catch, which was preserved in 10 percent formalin. Fishes were identified as to species using the key made by Miller and Lea (1973). Reference was made to museum collections at the California Academy of Sciences to verify the identifications of some juvenile forms. Each fish was measured, weighed, and examined for skin tumors (papillomas). Total length measurements, (i.e. from the tip of the snout to the tip of the tail) were taken on all sharks, skates, and rays. Standard length measurements (i.e. from the tip of the snout to the end of the vertebral column) were taken on the remaining species. Representative specimens of each species were preserved in 10 percent formalin and deposited at the California Academy of Sciences in San Francisco.

Invertebrates were identified to the lowest taxon possible using published keys, and enumerated. Crabs of the genus *Cancer* were identified as to species, sexed, and measured. The size of these crabs is expressed as the shoulder width, which is a caliper measurement of a straight line distance across the carapace immediately anterior to the outermost spines.

Selected specimens of English sole, speckled sanddab, and Dungeness crab were retained for analysis of heavy metals and chlorinated hydrocarbons. The procedures used were the same as those outlined in Chapter 4.

PHYSICAL AND CHEMICAL SEDIMENT CHARACTERISTICS

The heavy metal concentrations in the sediment samples collected at the seven stations for a three year period are shown in Fig. 5-6. The data indicate that,

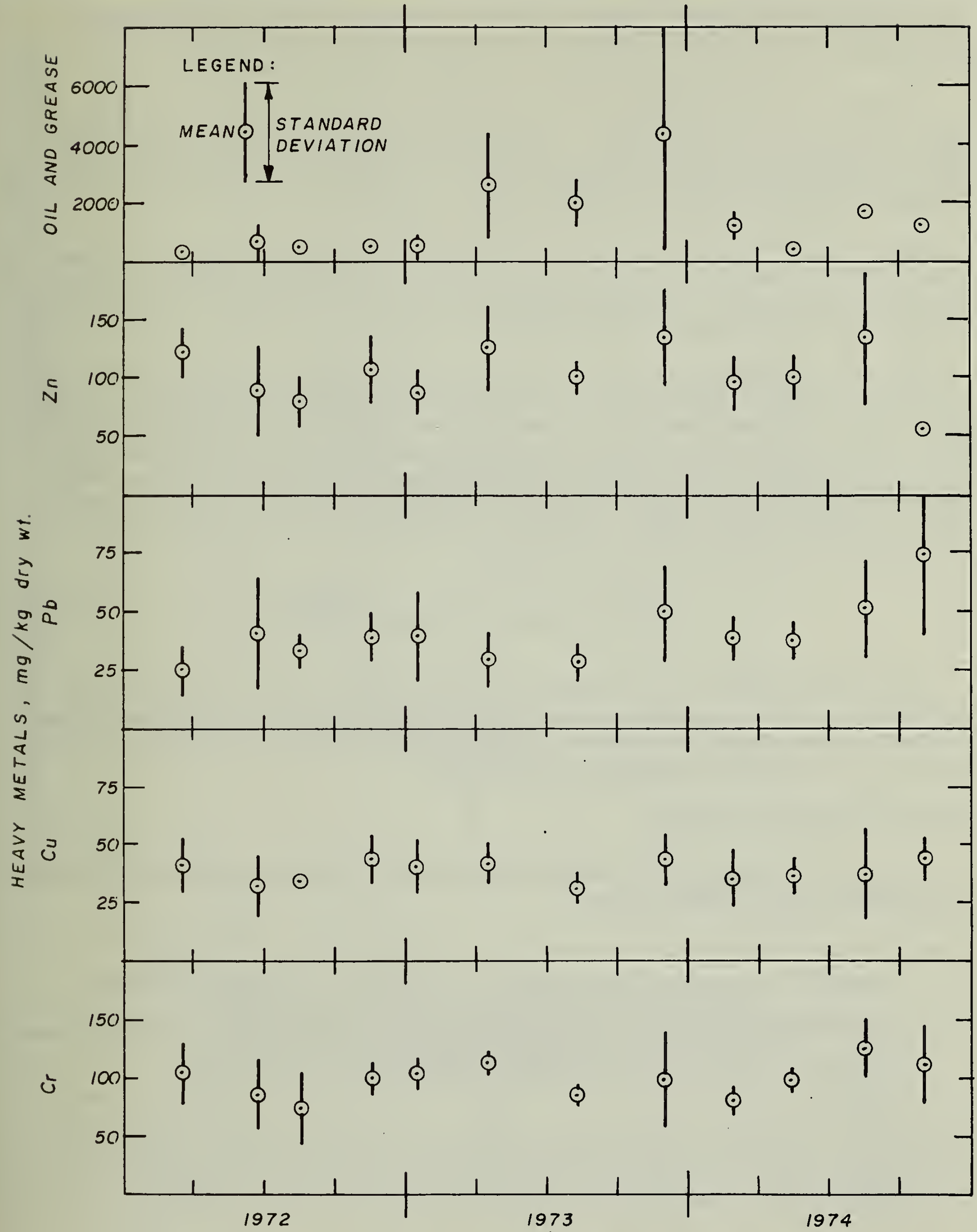


Fig. 5-6. Heavy Metals Concentration in Sediment Samples Collected from the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay, 1972 to 1974

during this period, concentrations of heavy metals have remained fairly uniform throughout the study area and were generally low with respect to the limits set by the EPA for heavy metal concentrations in dredge spoils (Table 5-2).

Figure 5-7 shows the observed concentrations of oil and grease, percent hydrocarbon, and total sulfides. The oil and grease generally averaged less than 1,000 mg/kg. The average concentration increased to 4,340 mg/kg in 1973 and dropped back below 1,000 mg/kg in 1974. No patterns were observed in the percent hydrocarbon and total sulfide data.

The results of the analyses of twelve samples collected in February 1974 are summarized in Table 5-3. The concentrations of most metals were low. The exception was mercury, with concentrations ranging from 0.337 to 3.09 mg/kg; the latter value was found at Station N8-15.

The only available data on the grain size composition of the sediments were obtained by the U.S. Army Corps of Engineers from samples collected May 3, 1971 (Fig. 5-8). Core samples up to 7.5 feet long were collected and analyzed in 2.5 foot increments (Table 5-4). The predominant sediment type was silt-clay with a low sand fraction. Field observations that were made since 1971 by the staff of Environmental Quality Analysts, Inc. also indicate that the sediments are predominately silt-clay in composition, although a greater proportion of sand has been noted in the most recently collected samples.

BOTTOM TRAWL CATCH RESULTS

Discussed below are data obtained on benthic fishes, benthic invertebrates and the chemical characteristics of selected species of fishes and Dungeness crabs. A literature review on the species of fishes and invertebrates that have some economic or ecological importance is appendixed.

Fishes Collected in Trawls

The benthic fishes are discussed below in terms of general composition and the incidences of tumor-bearing fishes.

Table 5-2. Maximum Concentrations of Pollutants Allowed for Marine (Shallow) and Estuarine Dredge Spoil Disposal

Pollutant	Maximum Spoil Concentration, mg/kg dry weight
Mercury	1.5
Cadmium	3.0
Lead	180
Zinc	300
Oil and grease	4000

[a] Limits set by the Environmental Protection Agency, Region IX in October 1974. These limits are presently being reevaluated.

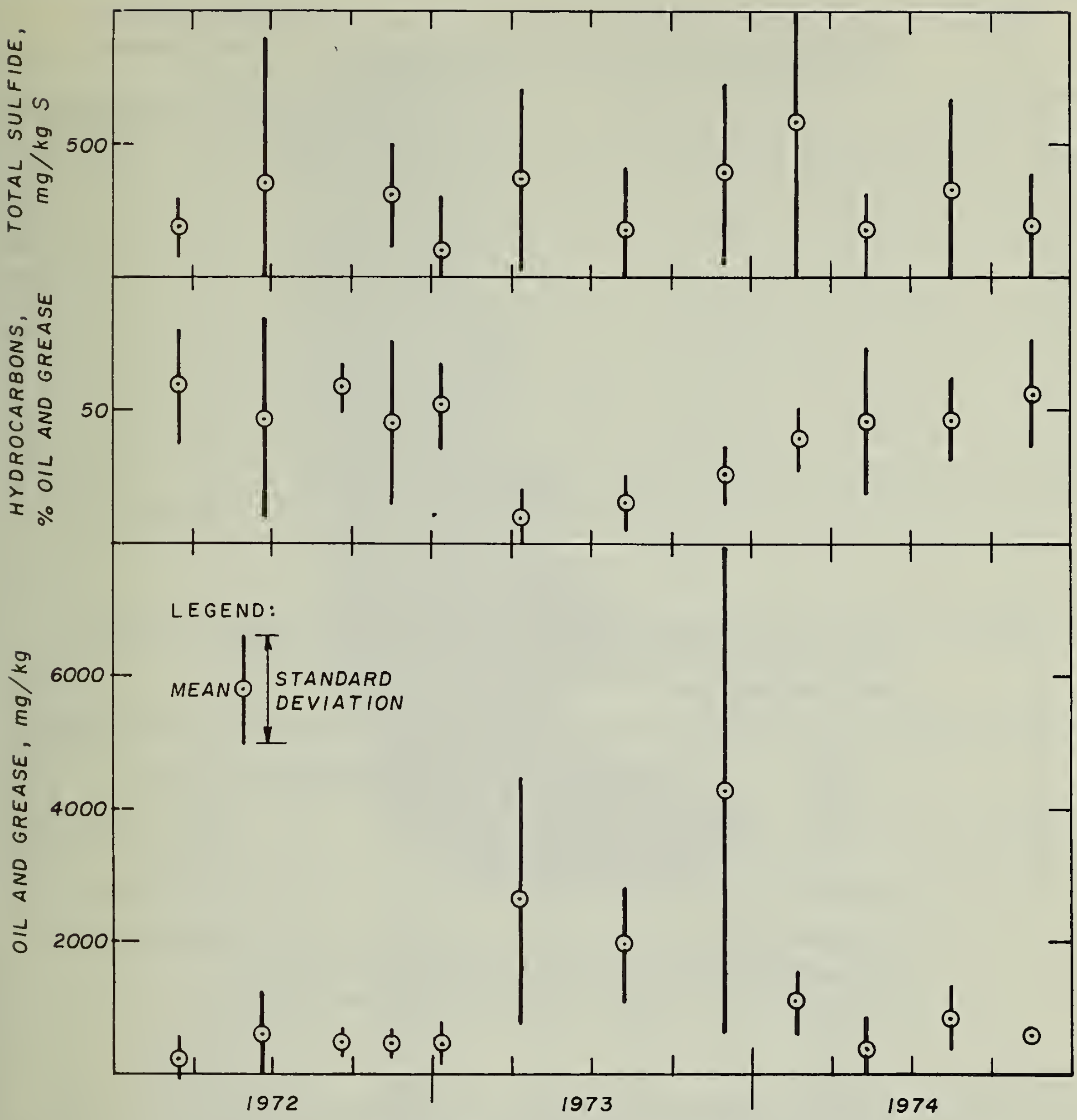


Fig. 5-7. Total Sulfide, Percent Hydrocarbons, and Oil and Grease in Sediment Samples Collected from the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay, 1972-1974

<u>General Composition</u>. Thirty-four species representing 20 families were collected during the study. A taxonomic list of these species is given in Table 5-5. The total number and weight of each species are summarized in Table 5-6. A combined list of the species of fishes collected in this study and in other studies from the general area is appendixed.

The five most commonly collected species comprised 76.5 percent of the catch and were the northern anchovy, speckled sanddab, shiner surfperch, brown rockfish, and English sole. The northern anchovy is a pelagic species which may have been collected coincidentally with the raising and lowering of the net. Their

Table 5-3. Heavy Metal and Chlorinated Hydrocarbon Concentrations in Sediment Samples Collected from the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay, February 1974

Station	Metals, mg/kg dry weight							Chlorinated hydrocarbons, mg/kg dry weight					
								Polychlorinated biphenyls				Insecticides	
	Cd	Cu	Cr	Hg	Ni	Pb	Zn	1242	1248	1254	1262	DDE	DDT
N5-7	1.67	28	97	0.241	92	28	78	0.06	<0.05	0.13	<0.05	<0.03	<0.03
N8-15	1.25	47	112	3.09	88	92	186	<0.05	<0.05	0.15	<0.05	<0.03	<0.03
N13-3	1.67	45	114	0.611	98	67	122	0.08	<0.05	0.38	<0.05	<0.03	<0.03
S4-10	1.18	54	129	0.482	124	58	140	0.05	<0.05	0.19	<0.05	<0.03	<0.03
S6-18	1.72	55	129	1.04	115	55	144	<0.05	<0.05	0.23	<0.05	<0.03	<0.03
N-3-1	1.11	38	107	2.09	09	43	103	0.05	<0.05	0.26	<0.05	<0.03	<0.03
N-4-4	1.00	33	109	0.405	96	70	90	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
O-4	1.06	34	101	1.11	94	42	93	0.19	<0.05	<0.05	<0.05	<0.03	<0.03
O-7	1.25	51	110	0.465	103	43	115	0.12	<0.05	<0.05	<0.05	<0.03	<0.03
O-10	1.70	49	131	0.491	98	49	148	0.06	<0.05	<0.05	<0.05	<0.03	<0.03
S-1-3	0.97	55	129	0.521	122	48	142	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03
S-4-5	1.15	25	96	0.337	94	33	77	<0.05	<0.05	<0.05	<0.05	<0.03	<0.03

Table 5-4. Grain Size Analyses on Sediment Samples Collected by Trawling in the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay, 1973-1974

Station	Station depth, feet	Percent sand[b]	Median grain size, mm	Sediment type
30	0-2.5	11	0.01	silt-clay
	2.5-5.0	<1	0.01	silt-clay
	5.0-7.5	16	0.02	silt-clay
31	0-2.5	10	0.02	silt-clay
	2.5-5.0	13	0.03	silt-clay
	5.0-7.5	41	0.04	sand-silt
32	0-2.5	43	0.06	sand-silt
	2.5-5.0	5	0.01	silt-clay
	5.0-7.5	5	0.01	silt-clay
33	0-2.5	53	0.08	sand-silt
	2.5-5.0	9	0.01	silt-clay

[a]Data from U. S. Army Corps of Engineers, San Francisco Region

[b]Percent sand is defined here as the fraction retained on a U. S. Standard Sieve No. 200

collection may have also resulted from difficulties in keeping the trawl net on the bottom during periods of maximum current. The remaining four species are all benthic fishes and are common in San Francisco Bay.

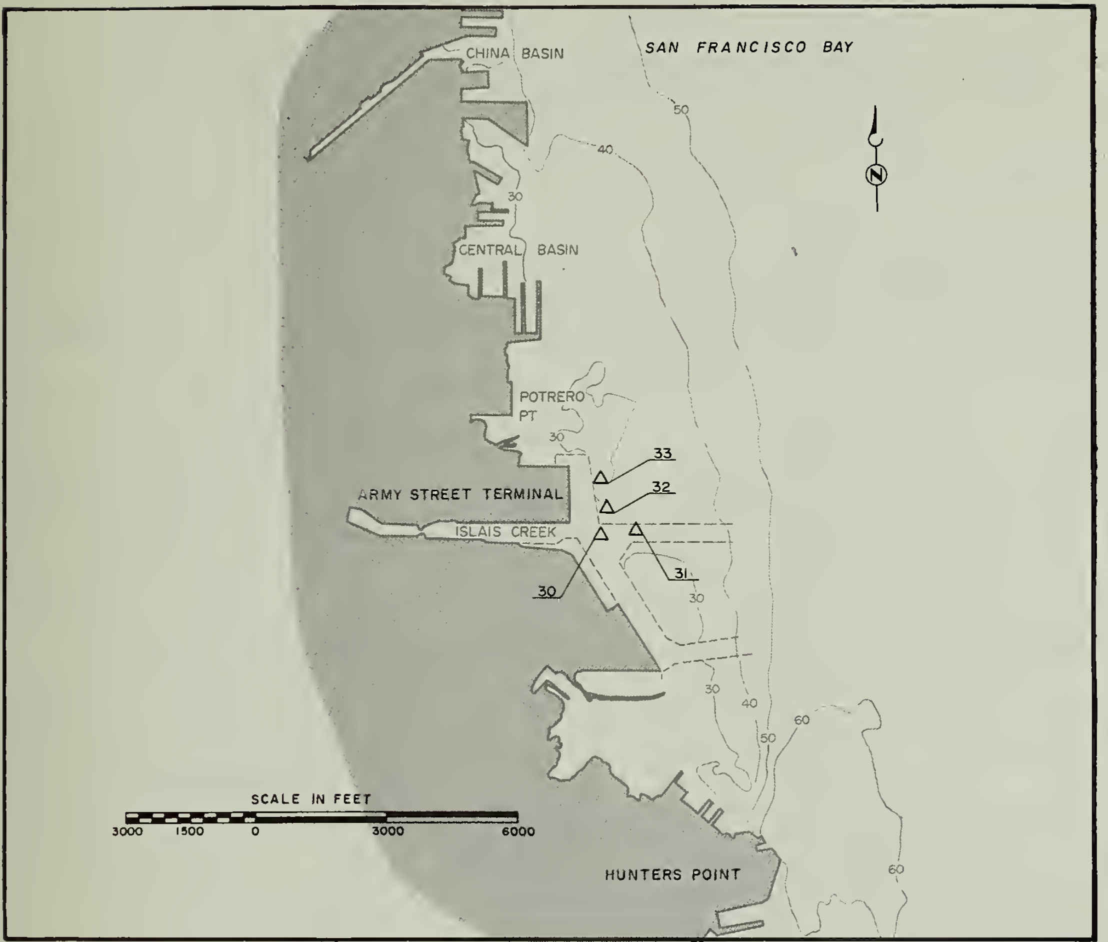


Fig. 5-8. U. S. Army Corps of Engineers Sampling Stations for Sediment Grain Size Analyses in the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay, 1971

Ten of the 34 species collected were collected on all four surveys. Twenty-one species were collected in the March and May 1974 surveys; 17 species were collected in December 1973; and 14 species were collected in October 1974. Variations in the number of species may reflect seasonal changes; however, the absence of a particular species from the collections does not mean the species was absent from the study area.

The majority of the catch was of juvenile fishes (Table 5-7). This was expected since San Francisco Bay is a known spawning and nursery ground for many of the species collected.

Tumor-Bearing Fishes. Only a single tumor-bearing specimen was collected during this study, a juvenile English sole, 29 mm SL, collected during the March 1974 survey. The presence of tumor-bearing English sole has been reported as composing as much as 6 to 36 percent of a single catch of this species in north San Francisco Bay (Herald and Innes, manuscript, 1965 ; Cooper and Keller, 1969).

Table 5-5. Common and Scientific Names of Fishes Collected from the Vicinity of Islais Creek, San Francisco Bay

Scientific name	Common name	Scientific name	Common name
Family SQUALIDAE		Family HEXAGRAMMIDAE	
Squalus acanthias	Spiny dogfish	Ophiodon elongatus	Lingcod
Family CARCHARHINIDAE		Family COTTIDAE	
Triakis semifasciatus	Leopard shark	Leptocottus armatus	Staghorn sculpin
Mustelus henlei	Brown smoothhound	Artedius notospilotus	Bonyhead sculpin
Family TORPEDINIDAE		Family SERRANIDAE	
Torpedo californica	Pacific electric ray	Roccus saxatilis	Striped bass
Family RAJIDAE		Family SCIAENIDAE	
Raja binoculata	Big skate	Genyonemus lineatus	White croaker
Family CLUPEIDAE		Family EMBIOTOCIDAE	
Dorosoma petenense	Threadfin shad	Rhacochilus toxotes	Rubberlip surfperch
Clupea harengus pallasii	Pacific herring	Hyperprosopon argenteum	Walleye surfperch
Family ENGRAULIDAE		Cymatogaster aggregata	Shiner surfperch
Engraulis mordax	Northern anchovy	Damalichthys vacca	Pile surfperch
Family OSMERIDAE		Phanerodon furcatus	White surfperch
Allosmerus elongatus	Whitebait smelt	Family GOBIIDAE	
Spirinchus thaleichthys	Longfin smelt	Lepidogobius lepidus	Bay goby
Unidentified osmerids	Unidentified smelt	Acanthogobius flavimanus	Yellowfin goby
Family BATRACHOIDIDAE		Family CYNOGLOSSIDAE	
Porichthys notatus	Plainfin midshipman	Symphurus atricauda	California tonguefish
Family OPHIDIIDAE		Family BOTHIDAE	
Chilara taylori	Spotted cusk-eel	Citharichthys stigmaeus	Speckled sanddab
Family GADIDAE		Family PLEURONECTIDAE	
Microgadus proximus	Pacific tomcod	Hypsopsetta guttulata	Diamond turbot
Family SYNGNATHIDAE		Parophrys vetulus	English sole
Syngnathus leptorhynchus	Bay pipefish	Platichthys stellatus	Starry flounder
Family SCORPAENIDAE			
Sebastes auriculatus	Brown rockfish		
Sebastes melanops	Black rockfish		

Benthic Invertebrates Collected in Trawls. Approximately 14 species of benthic invertebrates were collected and of these, 13 species were arthropods (Table 5-8). Only a single species of mollusk was collected, Busycotytus canaliculatus. This is a large eastern snail which was presumably introduced in the bay along with the eastern oyster, Crassostrea virginica (Smith and Carlton, 1975). Species of the genus Crago composed 80 percent of the 716 specimens of arthropods collected; Crago franciscorum, the bay shrimp, and C. nigricauda, the black tail shrimp, were the two most commonly collected. The remaining species, C. nigromaculata, the black spotted shrimp, was only collected on the May 1974 survey. The remaining species of arthropods were infrequently collected and represented by less than 50 individuals.

Chemical Analyses of Fishes and Dungeness Crab

English sole and speckled sanddabs collected from the December 1973, March 1974 and May 1974 surveys were analyzed for heavy metals and chlorinated hydrocarbons. Composites of whole fishes were analyzed when the specimens were

Table 5-6. Species of Fishes Collected by Trawling in the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay, 1973-1974

Species	December 1973		March 1974		May 1974		October 1974		Total	
	Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight
Northern anchovy	25	35	276	6134	52	679.5	4	20.5	357	6869
Speckled sanddab	20	141	170	1160	31	276.8	61	440	282	2017.8
Shiner surfperch	61	1007	116	1834	10	274	17	250	204	3365
Brown rockfish	24	602	105	1922	24	1529.5	24	2100	177	6153.5
English sole	2	62	63	2142	42	2429	6	62	113	4695
Pacific herring	42	207	1	6	12	109.9	11	63.5	66	386.4
Plainfin midshipman	1	0.5	1	2	48	2559.5	-	-	50	2562
White crocker	5	54	5	1063	25	3316	-	-	35	4433
Pile surfperch	5	140	14	964	1	398	13	1805	33	3307
Pacific tomcod	1	23	19	45	11	402	2	16	33	486
Staghorn sculpin	-	-	23	1259	3	107.5	-	-	26	1366.5
White surfperch	1	133	12	353	1	22	10	543	24	1051
Bay goby	1	4	10	32	9	35.5	2	10	22	81.5
Whitebait smelt	-	-	-	-	9	41.7	-	-	9	41.7
Smelt, unident	-	-	-	-	9	4.8	-	-	9	41.8
Starry flounder	1	657	1	498	-	-	2	2700	4	3855
Threadfin shad	4	72	-	-	-	-	-	-	4	72
Spiny dogfish	-	-	-	-	4	12,034	-	-	4	12,034
Longfin smelt	-	-	4	10	-	-	-	-	4	10
Lingcod	-	-	3	308	-	-	-	-	4	308
Bay pipefish	1	2	-	-	-	-	2	5	3	7
Bonyhead sculpin	1	63	2	22	-	-	-	-	3	85
Black rockfish	-	-	-	-	3	4.3	-	-	3	4.3
Walleye surfperch	1	33	-	-	1	2.5	-	-	2	35.5
Brown smoothhound	-	-	-	-	1	790	-	-	1	790
Yellowfin goby	-	-	1	42	-	-	-	-	1	42
Leopard shark	-	-	1	1950	-	-	-	-	1	1950
Pacific electric ray	-	-	-	-	-	-	1	374	1	374
Big skate	-	-	-	-	1	474	-	-	1	474
Spotted cusk-eel	-	-	1	66	-	-	-	-	1	66
Rubberlip surfperch	-	-	-	-	-	-	1	648	1	648
Striped bass	-	-	1	15.4	-	-	-	-	1	15.4
California tonguefish	-	-	-	-	1	19	-	-	1	19
Diamond turbot	-	-	-	-	-	-	1	202	1	202
Total	196	3235.5	829	19,966	298	25,509.5	157	9239	1481	57,950
Total number species	17 species		21 species		21 species		14 species		34 species	

small, as were most of the specimens. Filets were analyzed on the larger fishes. The results of the analyses are presented in the appendix. These data are baseline in nature, and no interpretations have been made.

SURVEYS OF THE BENTHIC INFAUNA

The major taxonomic components of the benthic infauna are shown in Table 5-9. A species list of the organisms collected is appended. Crustaceans composed about 70 percent of the total organisms collected on each survey. The gammarid amphipods Ampelisca milleri, Corophium sp., C. ascherusicum, and Photis sp were the numerically dominant crustacean species. The numerically dominant species of polychaete worms were Exogone lourei, Glycinde polygnatha, and an unidentified juvenile (Capitellid sp. or Mediomastus sp.). Mollusks, primarily Transennella tantilla, were also commonly collected.

Table 5-7. Size Ranges, Mean Sizes, and Sex Ratios of Fishes Collected by Trawling in the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay, 1973-1974

Species	Survey		Number measured	Size range, mm SL	Mean, mm SL	Sex ratio, M:F
Northern anchovy	December	1973	25	29 - 74	42	Juv
	March	1974	276	53 - 162	103	-
	May	1974	52	79 - 154	107	-
	October	1974	4	72 - 91	80	-
Speckled sanddab	December	1973	17	68 - 95	88	10:7
	March	1974	170	34 - 104	75	114:50
	May	1974	40	40 - 101	80	22:8[a]
	October	1974	61	28 - 93	66	34:22[a]
Shiner surfperch	December	1973	61	66 - 105	80	33:28
	March	1974	116	64 - 113	83	35:81
	May	1974	10	73 - 124	99	2:8
	October	1974	17	58 - 97	77	9:8
Brown rockfish	December	1973	24	58 - 179	79	-
	March	1974	105	54 - 199	74	Juv
	May	1974	24	69 - 190	115	5:0[a]
	October	1974	24	72 - 186	133	-
English sole	December	1973	2	104 - 141	-	Juv
	March	1974	63	53 - 231	115	2:2[a]
	May	1974	50	44 - 270	116	4:2[a]
	October	1974	6	80 - 88	84	Juv
Pacific herring	December	1973	42	63 - 82	71	Juv
	March	1974	1	75	-	-
	May	1974	12	41 - 51	45	Juv
	October	1974	11	71 - 82	78	Juv
Plainfin midshipman	December	1973	1	31	-	Juv
	March	1974	1	32	-	-
	May	1974	48	54 - 260	126	17:9[a]
White croaker	December	1973	5	60 - 289	84	1:0
	March	1974	5	188 - 215	204	-
	May	1974	25	101 - 280	182	10:7[a]
Pile surfperch	December	1973	5	84 - 109	96	0:5
	March	1974	14	93 - 205	120	0:8
	May	1974	1	245	-	1:0
	October	1974	13	90 - 210	147	4:9
Pacific tomcod	December	1973	1	110	-	-
	March	1974	19	110 - 134	119	Juv
	May	1974	11	109 - 165	137	1:1[a]
	October	1974	2	75	-	Juv
Staghorn sculpin	March	1974	23	102 - 176	129	-
	May	1974	3	73 - 160	-	0:1[a]
White surfperch	December	1973	1	172	-	1:0
	March	1974	12	74 - 152	103	0:8
	May	1974	1	94	-	1:0
	October	1974	10	90 - 165	119	1:9
Bay goby	December	1973	1	73	-	-
	March	1974	10	68 - 78	73	-
	May	1974	9	57 - 80	69	-
	October	1974	1	75	-	-
Whitebait smelt	May	1974	9	31 - 91	65	-
Smelt, unident	May	1974	9	34 - 41	38	-
Starry flounder	December	1973	1	322	-	-
	March	1974	1	272	-	-
Threadfin shad	December	1973	4	84 - 112	94	Juv
Spiny dogfish	May	1974	4	777 - 940	836	1:3
Longfin smelt	March	1974	4	58 - 65	-	-
Lingcod	March	1974	3	69 - 244	-	-
Bay pipefish	December	1973	1	177	-	-
	October	1974	2	133 - 185	-	-
Bonyhead sculpin	December	1973	1	128	-	-
	March	1974	2	50 - 194	-	-
Black rockfish	May	1974	3	41 - 65	-	Juv
Walleye surfperch	December	1973	1	100	-	0:1
	May	1974	1	50	-	-
Brown smoothhound	May	1974	1	661	-	1:0
Yellowfin goby	March	1974	1	162	-	-
Leopard shark	March	1974	1	84	-	-
Pacific electric ray	October	1974	1	265	-	-
Big skate	May	1974	1	415	-	1:0
Spotted cuskeel	March	1974	1	246	-	-
Rubberlip surfperch	October	1974	1	290	-	1:0
Striped bass	March	1974	1	194	-	Juv
California tonguefish	May	1974	1	127	-	1:0
Diamond turbot	October	1974	1	191	-	-

[a]Rest - juveniles

Table 5-8. Species of Macroinvertebrates Collected by Trawling in the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay, 1973-1974

Species	December 1973	March 1974	May 1974	October 1974	Total
Crago franciscorum	4	77	300	6	387
Crago nigricauda	9	4	109	16	138
Crago nigromaculata	-	-	49	-	49
Pisaster brevispinus	-	40	6	-	46
Heptacarpus spp.	1	-	23	-	24
brachyuran	7	-	-	15	22
Pagurus spp	3	-	3	8	14
Cancer productus	-	7	3	1	11
Cancer antennarius	-	-	-	7	7
Cancer gracilis	-	2	2	2	6
Pagurus hirsutiusculus	-	5	-	-	5
mysidacean	1	4	-	-	5
Cancer magister	-	1	1	-	2
Busycotytus canaliculatus	-	-	-	2	2
Total	25	140	496	57	718

Table 5-9. Total Number and Percent Composition of the Major Groups of Benthic Infauna Organisms Collected in the Vicinity of the Southeast WPCP Outfall[a]

Survey	Polychaetes		Mollusks		Crustaceans		Others [b]		Total number of organisms
	Total number	Percent composition	Total number	Percent composition	Total number	Percent composition	Total number	Percent composition	
March 1972	3,984	8.7	7,396	16.2	34,150	74.8	157	0.3	45,687
June 1972	5,885	10.7	8,945	16.3	39,987	72.8	127	0.2	54,944
September 1972	23,079	19.5	4,806	4.1	89,796	76.0	521	0.4	118,202
November 1972	44,871	38.0	3,243	2.7	43,960	37.2	2520	2.1	94,594
January 1973	9,499	27.6	476	1.4	23,931	69.5	516	1.5	34,422
April 1973	6,368	63.8	1,475	14.8	1,887	18.9	244	2.4	9,974
August 1973	5,662	9.9	1,034	1.8	50,040	87.3	575	1.0	57,311
November 1973	3,208	7.8	955	2.3	36,559	89.2	278	0.7	41,000
February 1974	675	4.2	520	3.2	14,405	89.1	565	3.5	16,165
May 1974	2,780	31.6	1,212	13.8	4,508	51.3	288	3.3	8,788
August 1974	2,120	12.2	810	4.7	14,274	82.1	184	1.1	17,388
October 1974	3,762	11.8	2,000	6.3	26,050	81.6	120	0.4	31,932

[a] Data from March 1972 to January 1973 and August and October 1974 are the total number of organisms per sample for seven stations. Data from April 1973 to May 1974 are the totals for twelve stations.

[b] Others include phoronids, nemerteans, oligochaetes, poriferans, platyhelminthes, sipunculids, echinoderms, and chordates. The presence of coelenterates, nematodes, and bryozoans were noted, but not enumerated.

An attempt was made to evaluate possible seasonal changes in numbers of certain components of the benthic infauna. A plot of total organisms of the three-year sampling period suggests that their numbers fluctuate seasonally with a peak occurring in early winter and a low occurring in early summer (Fig. 5-9). This curve is followed closely by the fluctuation in numbers of Ampelisca milleri, since it accounted for over 80 percent of the total number of organisms collected on the January and November 1973, and February and October 1974 surveys. Generally, percent compositions of A. milleri in the catch were highest during the winter months. Exogone lourei, the numerically predominant polychaete, was collected most commonly during the fall and least in winter and spring. This species ranged from 0.1 to 32.8 percent of the total numbers of organisms collected in the surveys. The pelecypod, Transennella tantilla, varied from 1.2 to 16.2 percent of the total organisms collected. No apparent seasonal pattern for this species is evident. A study specifically designed for quantitative analyses would be required to substantiate their apparent fluctuations.

The total numbers of infaunal organisms and species were examined to determine if any distribution patterns existed. Of particular interest was the possible relationship between the distribution of organisms and the proximity of each station to the Southeast WPCP diffuser. The data collected from May 1973 were used, since 12 stations were sampled during this period.

The distance of each station from the outfall was compared with the numbers of various taxonomic components of the benthic infauna from each respective station using product-moment correlation analyses (Table 5-10). No significant relationship was found between distance from the outfall and total numbers of organisms, number of taxa found, number of crustaceans, or number of mollusks collected at any one station. A significant negative correlation was obtained for the May 1973 data when distance and number of polychaete worms were compared. No significant relationships were found for polychaete worms in the remaining surveys.

Table 5-10. Correlation Analyses Between Distance of Sampling Station from Southeast WPCP Outfall and Various Components of Benthic Infauna

Survey	Correlation coefficients for distance compared with infauna				
	Total No. organisms	Number taxa	Number crustaceans	Number polychaetes	Number mollusks
May, 1973	0.57	0.33	0.43	-0.64*	0.52
August, 1973	0.00	0.16	0.01	-0.14	-0.15
November, 1973	-0.30	0.03	-0.31	-0.11	0.03
February, 1974	0.08	0.09	-0.08	-0.31	0.20
May, 1974	0.12	0.37	0.11	0.26	0.29

* - Significant at the 95 percent confidence level.

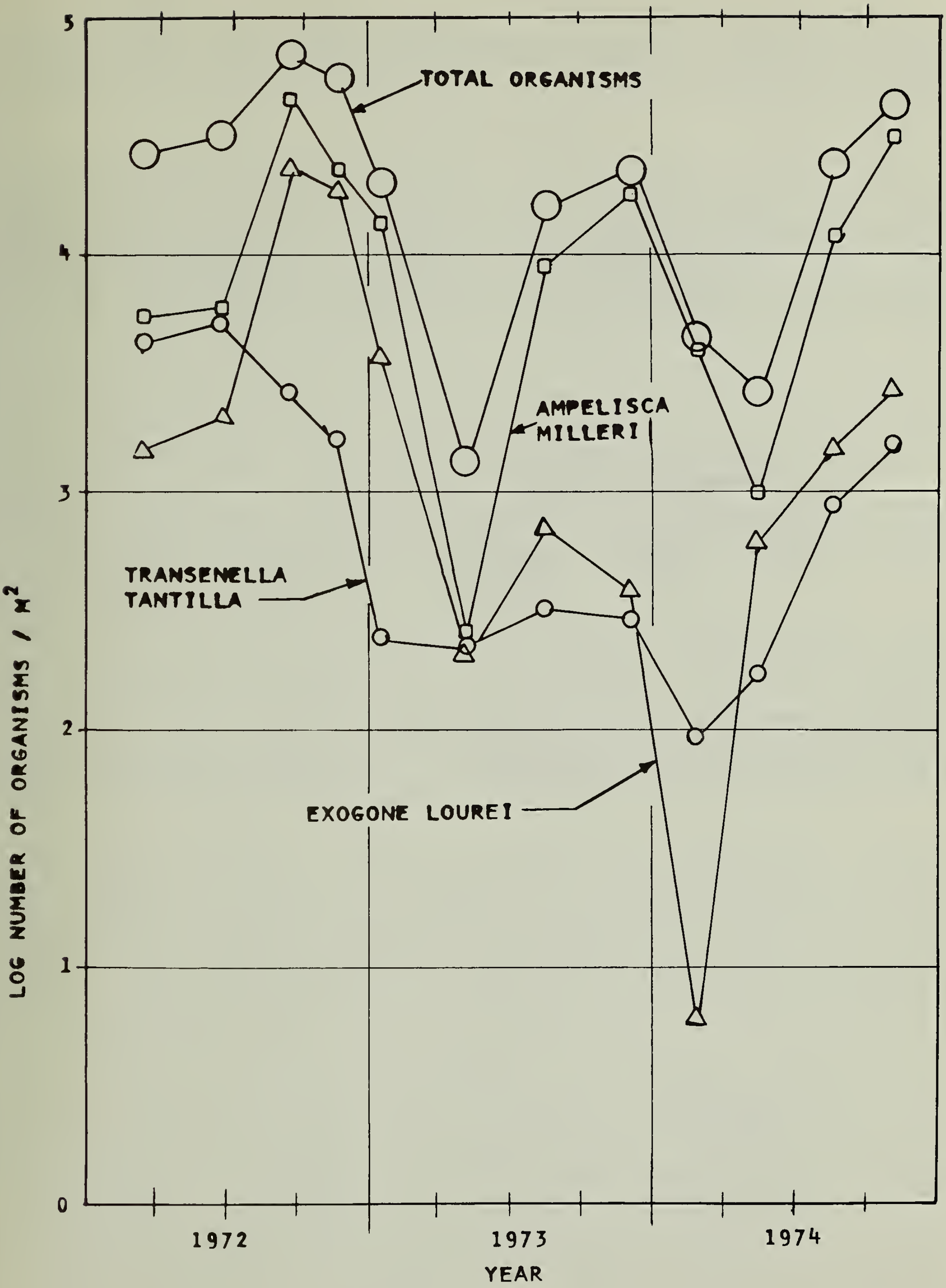


Fig. 5-9. Total Organisms and Predominant Species Collected in Dredge Samples from the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay, 1972 to 1974

To determine whether an analysis of spatial distribution was possible, using the data from only one composite sample from each station on each survey, five sets of composite samples were taken at several stations (Table 5-11). The resulting data showed there was considerable variation between replicates in the numbers of organisms collected.

The monitoring requirements for the Southeast WPCP have been changed effective with the first quarter of 1975. The seven stations that have been monitored since 1972 have been retained, but four samples from each station are now collected and analyzed separately. Also, a grain size analysis is made on one sample from each station. These new requirements will result in a more accurate picture of the distribution of the organisms. Much work remains to be done on the natural histories of the component species before the infaunal data can be interpreted.

Table 5-11. Comparison of Replicate Samples Collected from the Vicinity of the Southeast WPCP Outfall

Survey	Station	Number of composite samples	Volume of composite in liters, mean ± std. dev.	Number of organisms per composite sample, mean ± std. dev.	Number of taxa per composite sample, mean ± std. dev.
April 1973	N18-15	5	18.4 ± 1.1	1462 ± 607	25.4 ± 1.9
April 1973	S6-18	5	17.5 ± 1.8	314 ± 92	12.4 ± 1.5
August 1973	N1-3	5	16.2 ± 1.6	1680 ± 761	21.4 ± 3.4

CHAPTER 6

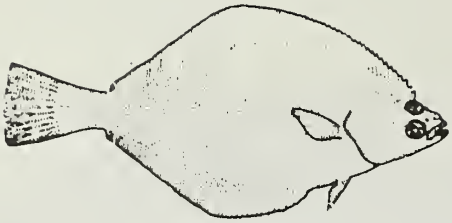
TOXICITY STUDIES

The toxicity of treated wastewater to marine organisms is an important consideration in the selection of a treatment process. Potential effluent toxicity must be evaluated whether the discharge is made to San Francisco Bay or to the Gulf of the Farallones. Although present federal requirements stipulate secondary treatment or its equivalent for dry weather flows, there are several treatment processes that can be used. A pilot plant test program was conducted by CH2M Hill, Inc. (1974) to determine which of the available processes would meet the existing discharge requirements. Concurrently, a toxicity study program was undertaken to test the toxicity of effluents from two of the alternative processes: (1) activated sludge, and (2) ferric chloride flocculation and sedimentation with and without filtration and activated carbon sorption. Local species of marine fishes and invertebrates representative of both the proposed bay and ocean disposal sites were used as test organisms. The overall purpose of the toxicity study was to obtain toxicity data for the higher treated effluents which could be used to evaluate the receiving water dilution criteria established for primary effluents in previous studies (Brown and Caldwell, 1971).

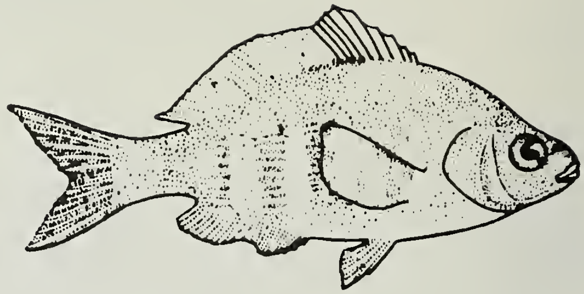
The toxicity testing program was begun by the City and County of San Francisco in 1970 when effluents from the city's three primary treatment plants were tested with a variety of local marine species (Brown and Caldwell, 1971). From the beginning of the program, special emphasis was placed on the immature stages of the Dungeness crab (Cancer magister) because of the concern for this species by the California Department of Fish and Game (DFG). Approximately 20 local marine species were also included in the program although none were tested in more than a few experiments.

Both the eggs and zoeae (larvae) of Dungeness crabs were tested in primary effluent samples to determine their tolerance. The results indicated the short-term exposure (96 hours) of zoeae to a 20 to 1 dilution of primary effluent would not reduce their survival rate. However, similar tests with Dungeness crab eggs resulted in the occurrence of a prolonged prezoeal stage in dilutions as high as 100 to 1. Eggs were observed to hatch into the prezoeal stage which did not then molt into a normal first stage zoeae. Since a prolonged prezoeal stage is an indication of stress conditions, the DFG recommended that the occurrence of these prezoeae be further investigated.

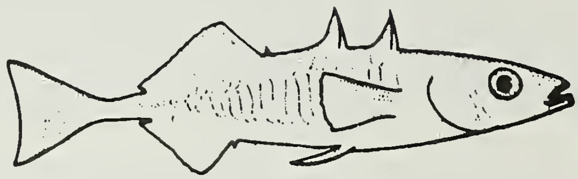
The Dungeness crab egg and larval studies were, therefore, continued through the 1971-72 crab hatching season, but the results of these additional efforts were inconclusive (Brown and Caldwell, 1973). Prolonged prezoeae stages occurred in seawater controls as well as in diluted primary effluent. This led to the belief that the incidence of these terminal prezoeae might be related to handling stresses instead of effluent toxicity. The crabs used as egg sources in the 1971-72 experiments had been shipped from as far away as Alaska. Because of continued concern over the incidence of the prezoeae, the DFG recommended that testing be continued through still another hatching season. This time the DFG recommended that only local crabs be used for egg sources, and that pilot plant effluents be used so that the effect on toxicity of upgrading the treatment process could also be evaluated.



English Sole
Parophrys vetulus
(x 3/5)

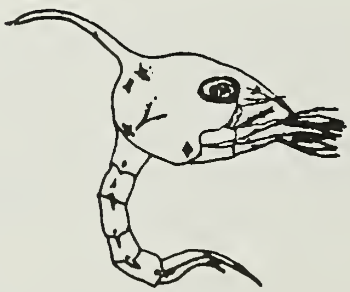


Shiner Surfperch
Cymatogaster aggregata
(Actual size)



Threespine Stickleback
Gasterosteus aculeatus
(x 2)

First Stage Zoea
(x 16)



Second Stage Zoea
(x 16)

Third Stage Zoea
(x 8)

Larval Stages of the Dungeness Crab
Cancer magister

Plate 6-1. Bioassay Test Organisms

The DFG also recommended that several additional species be included in the current testing program. Since shiner surfperch (Cymatogaster aggregata) and bay shrimp (Crago franciscorum) were among the species most sensitive to primary effluents (Brown and Caldwell, 1971), these species were selected by the DFG for additional testing in the pilot plant effluents. English sole (Parophrys vetulus) were also included because of their commercial importance. The results of these tests and the tests on Dungeness crab eggs and zoeae are reported in this chapter.

SCOPE OF THE TOXICITY INVESTIGATIONS

The study plan was to test the tolerance of the selected marine fish and invertebrate species to various concentrations of effluents from the pilot plant at the Southeast Water Pollution Control Plant (WPCP). The study was divided into two series of tests because of limited availability of test organisms. The first test series included shiner surfperch, English sole and bay shrimp, all of which were readily available during the summer months. Dungeness crab eggs and zoeae, however, could be obtained only during the winter crab hatching season, and therefore were tested in a separate series of tests.

The first series of tests was run in conjunction with the CH2M Hill, Inc. pilot plant project; a special pilot plant run was necessary to carry out the second series of tests. As originally planned, only pilot plant effluents using an influent feed from the Southeast WPCP service area were to be tested in the first test series. The pilot plant was scheduled to be in operation for 25 days during the summer, and effluent samples were to be collected and tested during this period. Subsequently, the city extended the first test series with an additional 25 day testing program. This included tests on pilot plant effluents using an influent feed composed of a three to one mixture of sewage from the North Point and Southeast WPCP, respectively. This mixture simulated the effluent that would be obtained if the two treatment plants were combined. The second series of tests was performed in the winter and utilized effluents entirely from the Southeast WPCP service area.

Since the toxicity study was performed concurrently with the pilot plant test program, the treatment process for dry weather flows had not yet been selected. The alternatives being tested in the pilot plant included two biological and three physical-chemical treatment processes, and there were options of collecting effluent samples at several stages during each process. It was impractical to test all of these options, and therefore testing was limited to one biological and one physical-chemical process. Those included were air activated sludge and ferric chloride flocculation and sedimentation, the latter with and without filtration and activated carbon sorption. These processes were selected after consultation with the city and with the concurrence of the San Francisco Bay Regional Water Quality Control Board (RWQCB) and DFG staffs. Tests on primary effluent samples, collected before and after post-chlorination, were also included in the study program for additional background information. These tests used samples collected from the North Point and Southeast WPCP, and the threespine stickleback (Gasterosteus aculeatus) was used as the test organism. Finally, the bioassay results of a separate monitoring program of untreated wet weather overflows are presented as additional pertinent information.

MATERIALS AND METHODS

This section presents a description of the materials and methods used in the toxicity studies. Since the results of bioassay tests are highly dependent on the methodology, the procedures are set forth in detail.

General Conduct of the Study

The toxicity studies were carried out in the laboratories of Environmental Quality Analysts, Inc. (EQA), an affiliate of Brown and Caldwell. The fish and shrimp bioassays were performed in EQA's San Francisco laboratory, and the crab bioassays were performed at EQA's facility in Burlingame, California. Additional facilities for holding stocks of fishes and egg-bearing crabs were obtained from Steinhart Aquarium, California Academy of Sciences, San Francisco, under a rental agreement. All laboratory work was performed by the EQA biological staff.

Test Facilities

A stainless steel environmental room was specially constructed for the testing program. This room was temperature controlled to within ±1 C. Illumination was by cool white fluorescent lighting and provisions were made for alternating light and dark periods. The interior was designed to allow for flexibility in experimentation. For the shiner surfperch, English sole, and bay shrimp bioassays, 40 liter (10 gallon) aquaria were placed on shelves along the walls and a 750 liter (200 gallon) tank was placed in the center for holding stocks of bay shrimp. The interior was modified for the Dungeness crab bioassays to include a continuous-flow seawater system with the 750 liter (200 gallon) holding tank used as a reservoir. Seawater was pumped through the 40 liter (10 gallon) aquaria and recycled through an activated charcoal filter and a 50 watt ultraviolet light disinfection unit. Each aquarium was fitted with a false bottom and an overlying layer of coarse sand, which served to filter the seawater and to prevent crab zoeae from escaping. All pipes and fittings used in this system were made of polyvinyl chloride to avoid heavy metal contamination.

Laboratory facilities for chemical and bacteriological analyses as well as the bioassays using threespine sticklebacks were provided by EQA's San Francisco laboratory. An auxiliary laboratory was also set up in Burlingame to assist in preparing test solutions and monitoring experiments.

Effluent Samples

The emphasis in this toxicity study was on testing more highly treated effluents. Most of the samples tested were, therefore, collected from the pilot plant located at the city's Southeast WPCP. When primary effluents were needed, these were obtained from either the North Point or Southeast WPCP according to requirements of particular experiments. The pilot plant in operation during the toxicity studies comprised a variety of biological and physical-chemical treatment processes. All of the processes are described in detail in the "San Francisco Wastewater Treatment Pilot Plant Study" report (CH2M Hill, Inc., 1974). The toxicity studies in

the present report are limited to effluents from three processes which were most likely to be adopted. Briefly, these processes are as follows:

1. Air activated sludge - conventional primary sedimentation followed by the activated sludge process with low pressure air.

2. Oxygen activated sludge - conventional primary sedimentation followed by the activated sludge process with low pressure oxygen.

3. Ferric chloride flocculation - primary treatment with ferric chloride addition, flocculation, and sedimentation with and without dual-media filtration and granular activated carbon sorption.

Effluents from all the above processes were tested in the fish and shrimp bioassays. Oxygen activated sludge was tested in preliminary experiments, and air activated sludge was tested throughout the series. Samples from both processes were collected from the secondary sedimentation tank effluents. Most of the physical-chemical samples were collected from the activated carbon column effluent, but effluents from the primary sedimentation tank were used in a few experiments towards the latter part of the test series.

Only the air activated sludge process and the primary stage of the physical-chemical process (flocculation and sedimentation) were operated during the special pilot plant run for the crab toxicity tests. The biological effluent samples were collected from the effluent of the secondary sedimentation tank, and the physical-chemical samples were collected from the primary sedimentation tank.

There were problems encountered with the physical-chemical effluents during both test series because of seawater intrusion into the influent sewage. During high tide, seawater entered the influent, raising the salinity. This higher salinity sewage formed a dense layer at the bottom of the sedimentation tank. At low tide, lower salinity sewage entered the sedimentation tank and passed directly over the dense layer to the weir. Thus the effluent still contained considerable quantities of floc. The effluent samples generally had to be resettled after collection, but substantial amounts of floc either remained in suspension or formed afterward.

Pilot plant effluents reflecting two influent feeds were tested in the fish and shrimp bioassay study. Effluent collected from August 10 through September 26, 1973 was from an influent feed derived entirely from the Southeast WPCP service area. From October 2 to 24, 1973, the influent feed was a three to one mixture of sewages from the service areas of the North Point and Southeast plants, respectively. The influent was 100 percent Southeast WPCP sewage during the entire crab bioassay study. The important difference between the two feeds is that sewage from the Southeast WPCP service area contains a large proportion of industrial wastes whereas North Point WPCP sewage contains relatively little industrial waste and is more dilute.

Primary effluents from the main plants were tested in two experiments with Dungeness crab zoeae and in monthly tests with threespine stickleback. The samples for the crab zoeae tests were collected from the Southeast WPCP upstream from the postchlorination point. Samples used for the stickleback bioassays were collected from the North Point and Southeast plants both upstream and downstream of the postchlorination point. At the Southeast WPCP, experiments with a chlorination-dechlorination system were being conducted, and chlorination for disinfection was carried out in the sump pump upstream from the sedimentation tanks. The

result of this was that chlorine residuals occurred in samples collected before and after the normal postchlorination point. None of the samples were dechlorinated prior to testing.

All effluent samples used in this study were 24 hour composites of hourly grab samples. The grab samples were refrigerated until collection was complete and then transported to the EQA laboratories where a composite was made. For the purposes of this report, the collection date is the date on which the sampling began; consequently, the first observation date in an experiment, which reflects 24 hour exposure to a particular effluent sample, is two days after the collection date.

Background Waters

Only marine organisms were used in this study; therefore, it was necessary to maintain the salinity at suitable levels in the experiments. Since wastewater effluents have a relatively low salinity, it was necessary to make an upward adjustment when high concentrations of effluents were tested. A standard salinity was chosen for each series of tests in an attempt to eliminate salinity as an experimental variable. A level of 28 parts per thousand (ppt) was used for the fish and shrimp tests, since this is a reasonable approximation of the ambient surface salinity of the local inshore waters during the summer months. The salinity standard was lowered to 25 ppt for the crab bioassays because this was the salinity level of the Steinhart Aquarium seawater.

Two salt preparations, a commercial sea salt and a synthetic formulation, were used to prepare dilution waters in addition to the natural seawater obtained from Steinhart Aquarium. The commercial preparation, referred to as "lobster salt" in this report, is manufactured by Leslie Salt Co. for the maintenance of lobsters. No problems were encountered with the survival of the fish and shrimp test species with this preparation, and it was used during the entire first series of tests. It was not possible, however, to test the adequacy of lobster salt seawater as a medium for rearing the immature stages of the Dungeness crab because of the limited period in which egg-bearing female crabs are available. For this reason, the lobster salt was only used as an experimental control. A synthetic formulation used by LaRoche, Eisler, and Tarzwell (1970) was substituted for use in the preparation of dilution water, since it had been shown to be a satisfactory medium for Dungeness crab eggs and zoeae by other investigators (D.V. Buchanan, personal communication, 1973).

Lobster Salt Seawater. In the fish and shrimp tests, dechlorinated San Francisco tap water was adjusted to 28 ppt with lobster salt for use as a control and as a dilution water. Effluent samples were mixed with the dilution water on a volumetric basis and then adjusted to 28 ppt by the addition of lobster salt to achieve desired salinity concentrations. In the crab tests, lobster salt was dissolved in deionized water to a salinity of 25 ppt. The solution was prepared in batches and filtered through a 0.45 μm pore size membrane filter before use. The storage and filtration procedure resulted in some deterioration which may have affected the survival of the test organisms. As a result, the controls using lobster salt seawater in the crab zoeae experiments were not considered valid.

Synthetic Seawater. Synthetic seawater was prepared with reagent grade chemicals in the same proportions as recommended by LaRoche, et al., (1970). The salts were dissolved in 500 liters of deionized water in the order given in Table 6-1. The salinity at this point was approximately 55 ppt. The salinity was adjusted to 50 ppt by further dilution and then filtered through a 0.45 μm pore size membrane

filter. The 50 ppt salinity was chosen because this made it possible to test wastewater concentrations up to 50 percent. The salinity was maintained at a constant level of 25 ppt by adding appropriate volumes of deionized water to the various effluent concentrations.

Table 6-1. Component Salts for Synthetic Seawater Stock

Salt	grams per 500 liters
Sodium fluoride as NaF	2.7
Strontium chloride as $SrCl_2 \cdot 6H_2O$	18.2
Boric acid as H_3BO_3	28.0
Potassium bromide as KBr	93.8
Potassium chloride as KCl	652
Calcium chloride as $CaCl_2 \cdot 2H_2O$	1,026
Sodium sulfate as Na_2SO_4	3,720
Magnesium chloride as $MgCl_2 \cdot 6H_2O$	4,660
Sodium chloride as NaCl	21,900
Sodium sulfite as $Na_2SO_3 \cdot 9H_2O$	18.2
EDTA (tetrasodium salt)	0.56
Sodium bicarbonate as $NaHCO_3$	186

Source: Adapted from LaRoche, Eisler, and Tarzwell (1970)

Steinhart Aquarium Seawater. Natural seawater with a relatively constant salinity of 25 ppt was obtained from Steinhart Aquarium and was used in the Dungeness crab egg and zoeae experiments. This seawater is pumped through sand in a specially constructed well located on Ocean Beach, adjacent to Golden Gate park, and was collected from the intake line prior to its entry into the Steinhart Aquarium system. Fresh batches were collected weekly to replenish the seawater in the recirculating system. This seawater was also used as a dilution water in the bioassay experiments after filtration through a 0.45 μm pore size membrane filter to remove naturally occurring microorganisms.

Deionized Water. Deionized tap water was used both as a dilution water and as a makeup water for the lobster salt and synthetic seawaters. Tap water was deionized by passing it through mixed bed ion exchangers. The deionized water had a specific conductance of 1 to 2 micromhos/cm.

Analytical Procedures

The effluent samples tested were not characterized chemically as part of this study; however, extensive chemical analyses were made during the course of the pilot plant study during September and October, 1973 (CH2M Hill, Inc., 1974). The available data on parameters for which discharge standards have been set are summarized in the appendix. Chemical analyses made on the pilot plant effluents used in the crab testing program were limited in scope. Results of five-day biochemical oxygen demand (BOD) and suspended solids tests for the air activated sludge process averaged 17 and 21 mg/l, respectively.

Several physical and chemical parameters were monitored during the course of the experiments, including dissolved oxygen, pH, temperature, and ammonia nitrogen. Chlorine residuals were measured on primary effluent samples collected after postchlorination. All procedures were in accordance with Standard Methods, 13th edition (1971).

Collection and Maintenance of Test Organisms

The collection and maintenance of an adequate supply of test organisms were the first major tasks in this study. The marine fishes and shrimp were collected from San Francisco and San Pablo Bay by commercial collectors. The shiner surfperch were captured in fish traps, and the juvenile English sole and bay shrimp were caught with a shrimp beam trawl. The sticklebacks were netted in

local streams with a small seine. Egg-bearing female Dungeness crabs were collected in the Gulf of the Farallones in crab traps by commercial crab fishermen, with special permission of the DFG. Each of these species posed special maintenance problems in the laboratory, primarily because of rough handling during collection.

Fishes and Shrimp. Specimens of similar size were selected for testing. To reduce variability in the experiments, those that were diseased or damaged were discarded. Shiner surfperch were up to 100 mm in length and most were mature. The English sole were juveniles, ranging from 80 to 100 mm in length. The sticklebacks were 30 to 40 mm in length and were of mixed age composition typical of those used locally as bioassay organisms. Bay shrimp were culled from samples containing a mixture of species, and individuals approximately 50 to 80 mm in length were used for testing.

Shiner surfperch were found in preliminary experiments to be particularly susceptible to bacterial fin rot disease. Consequently, all shiners were held and treated at Steinhart Aquarium prior to their use in the tests. The fishes were maintained in 950 liter (250 gallon) concrete tanks in which seawater was constantly replenished by Steinhart Aquarium's continuous-flow system. The temperature was maintained at a constant of 15 ±1 C. Although there is no universally accepted treatment for fin rot, several treatments have been recommended (Amlacher, 1970; Lagler, 1956). A malachite green and formalin treatment was used initially, but it was found that treatment with a concentrated formalin solution (38 percent) at a dose rate of 0.25 mg/l for one hour was adequate. This treatment was administered at two-day intervals during a six-day period. The fish were regularly fed on a diet of live brine shrimp and minced clams during this time.

The incidence of bacterial fin rot disease is probably related to injuries or stress sustained through rough treatment during capture, holding, and transport. It usually results in death, but some fish survive for extended periods with their entire caudal fin eroded away and a portion of their vertebral column exposed. Injured fishes were most susceptible to this infection; however, bacterial fin rot is very contagious once established. Therefore, particular effort was made to remove any fishes with visible evidence of injury or disease.

English sole were not as susceptible to bacterial fin rot. Initially, these fishes were treated and maintained at Steinhart Aquarium in the same manner as the shiners, but they damaged their snouts on the abrasive concrete tanks. Therefore, they were subsequently kept in a 950 liter (250 gallon) glass aquarium at EQA laboratory in San Francisco. There the fishes were maintained in a recirculating seawater system at 13±1 C. The seawater, obtained from Steinhart Aquarium, was continuously purified by a sand filter and ultraviolet disinfection unit. Although bacterial fin rot was not a problem with this species, the fishes were dosed with malachite green at 0.3 mg/l as a prophylactic measure. The malachite green persisted for approximately one day and then gradually disappeared.

Stocks of sticklebacks were maintained in glass aquaria at a temperature of 20±1 C. The water was a mixture of dechlorinated tap water and San Francisco Bay water with a salinity of approximately 15 ppt. The only maintenance problem was the occasional occurrence of parasitic gill copepods in several batches of fishes. These parasites often went unnoticed, but on several occasions increased mortality rates were attributed to the parasitic infestations.

Bay shrimp were found to be a difficult species to maintain in the laboratory. Shrimp were obtained from commercial trawlers and were there by subjected to rough handling procedures. The handling stresses undoubtedly caused many of the mortalities that occurred in the experiments, both in the control and effluent dilutions. Because of the problems of maintaining the species, the bay shrimp were used in experiments as soon after collection as possible. Only active, undamaged specimens were selected for use in the tests. The stocks were held in a 750 liter (200 gallon) polyethylene tank at 13 ± 1 C, and were fed brine shrimp daily. Mortality in the holding tank was high.

Dungeness Crabs. The limiting factor in the performance of the Dungeness crab egg and zoeal tests was the availability of an adequate supply of healthy, mature eggs. The hatching period in nature occurs during the winter, but the exact time varies from year to year. This made it necessary to begin the collection of egg-bearing crabs in mid-November. Initially, attempts to collect specimens using bottom trawls and crab traps were unsuccessful. Female crabs were either not in the area being fished or were not feeding. By mid-December, however, a number of gravid crabs had been collected, but none of the egg masses were mature and ready to hatch. This made it necessary to maintain the crabs in captivity until egg development was complete.

Gravid crabs were held at Steinhart Aquarium in the same concrete tanks which had been used previously for holding the shiner surfperch. Filtered seawater was pumped continuously through each tank to prevent stagnation, and concrete blocks were placed on the bottom of each tank to simulate natural shelters. The crabs were offered food daily, but most did not eat during the holding period. Weekly checks were made to determine the progress in egg development.

When the crabs were collected, the egg masses were light orange in color which characteristically indicates hatching will not occur for four to six weeks. As development progressed, the egg masses gradually changed to a dark orange-brown color. The egg masses were then checked at daily intervals and samples of eggs were removed from the crabs for microscopic examination. Observations included checking for a pulse in the eggs and assessing the overall condition of each egg mass. The outer layers of the egg masses of most crabs were found to be sloughing off because of the constant rubbing against the abrasive concrete surfaces of the holding tanks. In addition, growths of colonizing bacteria and other commensal organisms were found on most of the egg masses. Although these organisms are probably found on most egg masses in nature, the growths on the egg masses of captive crabs appeared abnormally heavy. Consequently, freshly captured crabs were used as egg sources in place of those which had been kept in the holding tanks whenever possible.

By mid-January, fresh egg-bearing female crabs were readily available, and the egg masses of these crabs appeared to be fully developed. Care was taken to select crabs with egg masses which were dark orange-brown in color and relatively free of bacterial growths. In spite of these efforts, hatching occurred from several days to two weeks after capture. Although the hatching period could not be predetermined exactly, it was possible through careful observation of the egg masses to estimate the time within two to three days.

All crabs brought to the laboratory were named alphabetically in order of their arrival, and those used in the experiments are listed in Table 6-2. Most of the crabs used had light growths of bacteria on the eggs. After mid-January, only

crabs which had not been kept in captivity for more than two weeks prior to hatching were used for the experiments. The hatching dates shown in the table refer to the first observation of zoeae. Generally most of the hatching was completed within two to three days, but in some cases, Crab M for example, the hatch extended over a much longer period. The experiments performed with each crab hatch are also shown in the table. Experiments were designated by retaining the crab letter identification, followed by "H", a number, or "C" for hatching experiment, acute toxicity experiment, and chronic toxicity experiment, respectively.

Table 6-2. Crabs Used in Toxicity Experiments in 1973 and 1974

Crab	Date of collection	Time held at Steinhart Aquarium	Bacterial growth on egg mass	Date hatch began	Experiments		
					Egg hatch	Acute	Chronic
C	early Dec.	2-4 weeks	light	Jan. 3	-	C-1	-
E	early Dec.	2-4 weeks	light	Jan. 1	E-H	E-1, E-2	E-C
F	early Dec.	2-4 weeks	heavy	Jan. 9	-	F-1, F-2 F-3	-
G	early Dec.	2-4 weeks	heavy	Jan. 18	-	G-1	-
H	Jan. 14	-	light	Jan. 25	H-H	-	-
M	Jan. 17	-	light	Jan. 25	M-H	-	-
N	Jan. 17	-	light	Jan. 27	-	N-1	-
P	Jan. 17	-	light	Feb. 4	-	P-1	-
R	Feb. 15	-	light	Feb. 20	-	R-1	R-C

Experimental Design

Both acute and chronic toxicity bioassays were used to measure toxicity. As used in this report, the term acute toxicity bioassay test refers to 96 hour bioassays comprising one or more experimental controls and several concentrations of effluent from the treatment processes being tested. The term chronic toxicity bioassay test refers to experiments of longer duration than 96 hours. The actual length of the chronic tests depended on the availability of effluent and test organisms although the original plan was to perform 25 day experiments. Each chronic experiment included one experimental control and several wastewater concentrations from each treatment process being tested.

All bioassays were batch tests run under static conditons. In the fish and shrimp toxicity experiments, the same test solutions were used for the duration of the test. These experiments were run in accordance with the general procedures outlined in Standard Methods, 13th edition (1971) and were intended to be comparable to the acute toxicity bioassays using sticklebacks which are normally required by the RWQCB for effluent monitoring programs in the San Francisco bay area. The crab toxicity tests were more experimental in nature and the test solutions were changed on a daily basis. Thus, these tests represented an intermediate between the standard 96 hours static bioassay and a continuous flow test. The test solutions in all chronic toxicity bioassays were also changed daily, but

in these tests the change was necessitated by the fact that the character of the wastewater sample would itself change markedly over a long period.

The concept of an experimental control raised some problems during the course of this study, and the philosophy used to resolve these problems is set forth here. The most important point is that the experimental control was regarded as a reproducible test conditon which was intended to serve a reference point for the other test conditons. The experimental control was not intended to represent either ideal conditions for the particular test species or the conditions confronting the test species in the natural environment. Therefore, there is no a priori reason why survival must be higher (or lower) in the experimental control than in a test condition with wastewater added. Two criteria were used in selecting a dilution water as a control for a set of tests: (1) the ability of the organism to survive in the control solution, and (2) the versatility of the solution with respect to maintaining constant salinity conditions. The ability of the test organisms to survive was measured in preliminary tests for the fish and shrimp species, but all three background waters were used in the bioassays with crab zoeae because of the limited duration of the crab hatching period.

The criterion used for a valid acute toxicity bioassay experiment in this study was 80 percent or greater survival in the controls. The results of those experiments in which this criterion was not met are omitted from the discussion in the text, but the results are presented in the appendix. The same criterion was used as a guideline for the chronic toxicity experiments, although in these chronic toxicity experiments with Dungeness crab larvae slightly lower survival percentages were accepted because of the difficulties experienced in maintaining crab zoeae over extended periods.

Fish and Shrimp Toxicity Tests. The emphasis in this series of tests was to obtain acute toxicity data on effluents from as many days of pilot plant operation as possible. This was done to account for the day-to-day variability in effluent quality. Longer term bioassays were also run to augment the acute toxicity data, but the duration of these tests was governed by the availability of effluents.

Several preliminary experiments were run to determine the toxicity range of the effluents. A variety of effluent concentrations ranging from 1 to 100 percent were tested, but only 10, 50, and 100 percent effluent concentrations plus a control were used once the toxicity range was established. Experiments were scheduled so that effluent samples from each treatment process were tested with two species on each of four consecutive days. An off-day was allowed for cleanup and then the cycle was repeated. This was the maximum amount of testing that could reasonably be undertaken with the facilities available. Shiner surfperch were used in most of the tests because of their availability. English sole and bay shrimp were used as the second test species, according to their availability. A stickleback bioassay was also run with each experiment for reference purposes. Ten organisms were used in each test condition, except in the initial bay shrimp bioassays where 20 organisms were used. The number of shrimp tested was subsequently reduced to facilitate handling. Temperature was maintained at 13±1 C, and salinity was adjusted to 28 ppt in all effluent concentrations using lobster salt. Dissolved oxygen, temperature, and pH were monitored daily, and ammonia nitrogen was spot checked as a precautionary measure.

The chronic bioassays were run in the same manner as the 96 hour tests except that test solutions were replenished daily and the test organisms were fed daily. Only shiner surfperch and English sole were used in these tests because of the difficulties involved in keeping bay shrimp alive for long periods under laboratory conditions. The first chronic test was run for 12 days and was terminated when the pilot plant influent feed was changed from 100 percent Southeast WPCP sewage to a mixture of North Point and Southeast WPCP sewage. The second set of tests ran for 23 days and was terminated when the pilot plant testing program ended.

Crab Toxicity Tests. Three types of experiments were performed in this series of tests: 96 hour egg hatching bioassays, 96 hour acute toxicity bioassays, and 15 to 25 day chronic bioassays. As with the first series of tests, an effort was made to obtain acute toxicity data, supplemented by chronic toxicity data, on effluent samples from as many different days of pilot plant operation as possible. Both eggs and first stage zoeae were used in the acute toxicity experiments, and first stage zoeae were used in the chronic tests.

Egg Hatching Experiments. Four experiments were run to determine the effects of the pilot plant effluents on egg hatching and the subsequent molt into first stage zoeae. Eggs from a different crab were used for each experiment so that a comparison of experiments would provide information on biological variability as well as the variability in the quality of the effluents tested. Three replicates with approximately 20 eggs each were tested for each experimental condition to determine the variability within each experiment.

The same experimental design was used for all four experiments. Three sets of controls, including Steinhart Aquarium seawater, lobster salt seawater, and the synthetic seawater, accompanied each experiment. A salinity control with Steinhart seawater diluted with 10 percent deionized water was also added. Both the activated sludge effluent and the ferric chloride flocculation and sedimentation effluent were tested at 1, 5, 10, and 50 percent concentrations. Steinhart seawater was used as the background water for the 1, 5 and 10 percent concentrations; synthetic seawater was used for the 50 percent concentration. An extra set of 10 percent ferric chloride flocculation effluent samples, brought to volume with synthetic seawater, was added as a check against the effect of the different background waters. In the first experiment, a similar check with 10 percent activated sludge effluent diluted with synthetic seawater was included. Also sets of 10 percent concentrations of each effluent, diluted with Steinhart seawater plus a spike of double strength artificial seawater sufficient to adjust the salinity to the level in the controls, were added as additional salinity checks.

The purpose of the experimental design was to permit the testing of several factors simultaneously. First, the three control solutions could be compared to determine whether or not the various background waters could be interchanged without effect. Second, the effects of different salinities could be separated from the effects of wastewater effluents. Third, the effects of increasing concentrations of each wastewater effluent could be determined. Fourth, the effect of the two treatment processes could be evaluated by comparing the overall percentage of first stage zoeae obtained from the original number of eggs.

Each egg hatching experiment was run for 96 hours. This length of time was chosen arbitrarily, and the practicability of it depended on starting the experiment with eggs which were ready to hatch. Timeliness was estimated by the hatching success in the controls. In three of the experiments, those using eggs from crabs E, H, and M, the timing was adequate, since most eggs had hatched in the controls

by 96 hours. In the experiment using eggs from Crab L, however, hatching in the controls took longer than 96 hours. The experiment was prolonged an extra day, but many of the eggs still did not hatch in either the controls or the wastewater dilutions. The data from this experiment are excluded from the text but are shown in the appendix. For purposes of analysis, however, all data were taken from the 96 hour results to maintain consistency among experiments.

Each crab to be used as an egg source was isolated in a holding tank until hatching began. When the hatching appeared to be progressing normally, the experiment was set up. Eggs were carefully removed with forceps from the outer layers of the egg mass close to the abdominal flap. All eggs were placed in Steinhart seawater for an hour after removal to allow any hatching stimulated by the stress removal process to occur prior to placing them in test solutions. The eggs were carefully examined under the microscope, and only those with vigorous internal movement and little or no external bacterial growth were selected for testing. Extreme care was taken to separate the eggs so that the cuticular layers and, if possible, the attachment stalk, remained intact. Approximately 20 eggs were placed in the test solutions in 250 ml Erlenmeyer flasks, and incubated in the environmental room.

Daily observations were made during the course of each experiment. The contents of the flasks were removed and examined. The number of unhatched eggs, prezoeae, and first stage zoeae were noted. The first stage zoeae were then removed, and the remaining eggs and prezoeae were carefully transferred to fresh media with pipettes. The old solutions were tested for dissolved oxygen, pH, and in some cases, ammonia. Bacterial plate counts were made on the controls and 50 percent wastewater dilutions.

Acute Toxicity Experiments. These experiments were designed to determine the 96 hour acute toxicity of the pilot plant effluents. All experiments included three background waters as controls and 10, 20, and 50 percent concentrations of each pilot plant effluent; extra test conditions were added to some of the experiments. In twelve experiments the salinity was adjusted to 25 ppt, and in two experiments the salinity was approximately 12 ppt. The synthetic seawater was used as the background water for the salinity adjustments. Effluent concentrations greater than 50 percent were not tested because this would have required an extra addition of salt to maintain a constant salinity level, and it is unlikely that crab zoeae would ever be exposed to wastewater at these concentrations in the natural environment.

A new experiment was begun each time a healthy batch of zoeae hatched. Zoeae were collected from the holding tank with a pipette and placed in a bowl containing Steinhart seawater. The zoeae had hatched the previous night and were generally only a few hours old when an experiment was begun. Ten zoeae were pipetted into each of the three replicate test solutions contained in 250 ml Erlenmeyer flasks. Each test solution was made up to a volume of 200 ml and placed in the environmental room for temperature equilibration prior to the set up of the experiment. All transfers of zoeae both during set up and subsequent observations were performed in the environmental room. Observations were made at 24 hour intervals for 96 hours. The test solutions were replenished daily to prevent an excessive buildup of bacteria and to prevent changes in the chemical nature of the effluent. The zoeae were counted and their condition noted; dead zoeae were removed. The survivors were pipetted into fresh media and incubated for another 24 hours. Zoeae were not fed during the course of the experiment.

Several chemical parameters, including dissolved oxygen concentration, pH and ammonia-nitrogen were measured in the test solutions after the zoeae had been removed. Bacterial plate counts were also made as time permitted. The purpose of these measurements was not to characterize the wastewater effluents, but to establish some guidelines for experimental test conditions. If die-offs occurred in the controls as well as the wastewater dilutions, these parameters would provide a starting point for determining the causative factors.

Chronic Toxicity Experiments. Two experiments were run to test the chronic effects of the pilot plant effluents, but because of the intensive labor requirements for these experiments, the number of test conditions was kept to a minimum. Steinhart seawater was used as the control and concentrations of 1, 5, and 10 percent effluent were tested for each treatment process. All conditions were tested with three replicates.

On a day-to-day basis, the chronic experiments were run much the same as the acute toxicity tests. Chronic experiments were begun with newly hatched first stage zoeae which were removed from the holding tank with a pipette. The zoeae were placed in freshly filtered Steinhart seawater and then into the test solutions, ten zoeae per flask. Daily observations were made and the test solutions were replenished. The one major departure in the conduct of this experiment from the acute bioassay experiments was that the zoeae were fed daily on newly hatched brine shrimp nauplii. Care was taken that only first stage nauplii were used; otherwise the nauplii would have been too large (Reed, 1969). As the crab zoeae molted into successively larger stages, this became less critical. An attempt was made to keep the number of nauplii constant, since the concentration of nauplii has been shown to affect survival (Gaumer, 1971). A sufficient number was placed in each test flask to give a concentration of approximately 10 nauplii per milliliter of test solution.

The original intention was to run two chronic bioassays for 25 days each. The first experiment was run for 25 days, running from January 3 to February 25, 1974, inclusive. The second chronic bioassay was run for 15 days beginning February 22 to March 9, 1974. This test was affected by a labor dispute which resulted in closure of the Southeast WPCP from March 8 through 16 so that effluent from the pilot plant was unavailable.

Methods of Data Analysis

The results of the fish and shrimp experiments are presented in the results section in a tabular format. The mean and standard deviation were calculated for results at comparable effluent concentrations. Median tolerance limits (TL_m) were calculated for the acute toxicity tests on primary effluents. Survival in undiluted pilot plant effluents was greater than 50 percent in virtually all the tests so the TL_m exceeded 100 percent.

The results of the experiments on the Dungeness crab eggs and zoeae are presented in the same manner as the fish and shrimp experiments. All the data are shown for the egg hatching experiments, but the means of the three replicates for each test condition are used in analyzing the acute and chronic toxicity results. The EC_{50} concentrations, which are the effective concentrations at which a particular response occurs in 50 percent of the test organisms, were calculated for the acute toxicity experiments. EC_{50} concentrations were calculated for reduced swimming activity caused by any factor including death. Where death is the only response considered, the term EC_{50} is equivalent to the TL_m.

Most of the experiments, from the first test series with fish and shrimp, as well as the second series with Dungeness crab eggs and zoeae were analyzed by chi-square analysis. Contingency tables, using a 2 by C format, were calculated for each set of experiments. Each experiment was analyzed individually, using the number of test organisms surviving and the number of mortalities for each concentration of effluent. The chi-square values for each experiment were summed and the resulting chi-square value was evaluated for statistical significance. This procedure is in accordance with the recommendations of the DFG staff at Menlo Park, California.

An analysis of variance was used in the analysis of the acute toxicity data. A two-way classification was used in accordance with the methods used by Sokal and Rohlf (1969) and Rohlf and Sokal (1969). The two-way classification permitted two variables to be analyzed, such as two treatment processes, each with several concentrations. In this case an interaction term is also calculated to help determine, for example, whether or not survival is affected by both treatment processes the same way when the concentration is increased.

The results of each analysis of variance are summarized in the table in the following format:

Analysis of Variance Table

Source of Variation	df	SS	MS	F_s	$F_{0.05}$	$F_{0.10}$
Subgroups	-	-	-	-	-	-
Factor A	-	-	-	-	-	-
Factor B	-	-	-	-	-	-
Interaction	-	-	-	-	-	-
Experimental Error	-	-	-	-	-	-

In this table Factors A and B are variables such as treatment process and effluent concentration. The terms "df", "SS", and "MS" refer to degrees of freedom, sums of squares, and mean squares, respectively. The "Fs" term is the calculated ratio of the respective subgroup to the variance from experimental error. The "Fs" term is then compared to the F-value that would be expected by pure chance; F-values are obtained from appropriate statistical tables. For the purpose of this report, the 95 percent confidence level ($F_{0.05}$) was accepted as the minimum standard for statistical significance.

RESULTS OF THE TOXICITY STUDIES ON FISHES AND SHRIMP

This section presents the results of the toxicity tests using shiner surfperch, English sole, threespine stickleback, and bay shrimp as test organisms. The results of acute toxicity tests on pilot plant effluents from the Southeast WPCP are discussed first, followed by the results of similar tests on the effluents from the mixture of North Point and Southeast WPCP sewage. The results of the long-term toxicity tests are discussed next, and finally the results of the monthly bioassays on the present primary effluents from the North Point and Southeast WPCP are

presented. The tables in the text summarize the results of the experiments with 80 percent or greater survival in the controls.

Acute Toxicity Tests on Pilot Plant Effluents from the Southeast WPCP Service Area

A total of 105 acute toxicity bioassays were run on pilot plant effluent samples collected from August 10 to September 26, 1973. Effluents from two biological treatment processes, air and oxygen activated sludge, were tested in preliminary experiments from August 10 to 22, 1973. Air activated sludge and ferric chloride flocculation and sedimentation effluents were tested from August 30 to September 26, 1973. The influent feed for all three effluents was from the Southeast WPCP service area.

Preliminary Tests. A series of preliminary tests were performed on the pilot plant effluents to determine the approximate toxicity so that fewer dilutions could be used in subsequent testing. Only effluents from the activated sludge processes were tested at this time because effluent from the ferric chloride flocculation process was not yet available. In total, nine concentrations of effluent were tested ranging from 1 to 100 percent effluent plus a control. The results of these tests are summarized in Table 6-3. Because of the preliminary nature of these tests, all results are shown even though the controls in some experiments do not meet the 80 percent survival criterion.

Low survival percentages were obtained with the shiner surfperch and bay shrimp in all effluent dilutions. Since survival was also low in the controls the mortality did not appear to be caused by effluent toxicity. The shiner surfperch used in tests with samples collected on August 10 and 11 were infected with bacterial fin rot disease. Severe fin erosion, primarily in the caudal fin, became evident within 24 hours in all dilutions as well as in the controls. Testing with shiner surfperch was, therefore, suspended until the disease could be controlled. All shiner surfperch were then held and treated prior to use in the tests as described in the section on the collection and maintenance of test organisms. The results of the tests with shiner surfperch on the effluent sample collected August 22 demonstrated that the bacterial fin rot problem was eliminated, since survival in the controls averaged 95 percent. The difficulties with the bay shrimp, however, were not as easy to diagnose. Shrimp were observed feeding on one another, but it could not be ascertained whether cannibalized individuals were dead or in a weakened condition prior to being eaten. To resolve this problem, shrimp were isolated in individual cages during subsequent tests. This increased the survival in the controls, but many of the experimental results had to be discarded because control survival was less than 80 percent.

In spite of the problems the results of the preliminary tests suggested that the effluent toxicity was low. For example, no English sole mortalities were recorded in the air and oxygen activated sludge samples collected August 20 and 21, 1973. Since the preliminary tests showed that toxic effects were not present at low concentrations, the number of effluent concentrations used for testing was reduced in subsequent experiments to three: 10, 50, and 100 percent effluent.

Table 6-3.
Preliminary Tests Showing Percent Survival of Test Organisms After 96 Hours Exposure to Activated Sludge Effluents (Southeast WPCP Service Area), 1973

Effluent, collection date and test organism	Effluent concentration, percent								
	0	1	2	5	10	20	33	50	100
Air, Aug. 10									
Shiner surfperch	50	90	60	50	50	60	60	30	40
Bay shrimp[a]	85	85	70	85	65	80	70	75	95
Oxygen, Aug. 11									
Shiner surfperch	30	90	50	40	30	10	40	10	0
Bay shrimp	75	75	70	90	85	85	70	75	70
Air, Aug. 20									
English sole[b]	100	100	100	100	100	100	100	100	100
Bay shrimp	85	75	-	-	90	-	70	70	90
Oxygen, Aug. 21									
English sole[b]	100	100	-	-	100	-	100	100	100
Bay shrimp	55	70	-	-	60	-	85	75	75
Oxygen, Aug. 22									
Shiner surfperch[b]	100	95	-	-	100	-	85	95	85
Bay shrimp	55	60	-	-	50	-	50	55	70

[a]20 bay shrimp were used in each replicate
[b]Data are means of two replicates

The air activated sludge effluents were the only biological effluents tested after the preliminary runs were made. It was not possible to test more than two treatment processes concurrently because of space limitations; therefore, when the effluent from the ferric chloride flocculation and sedimentation process became available, testing of oxygen activated sludge effluents was discontinued. The preliminary testing indicated that there was little or no detectable difference between the air or oxygen activated sludge processes with respect to acute toxicity.

Air Activated Sludge Effluent. Table 6-4 shows the results of the tests performed on the air activated sludge effluent samples from Southeast WPCP. The data are the survival percentages after 96 hours exposure to the respective effluent concentrations, and the dates listed refer to the beginning of the 24 hour sampling period. In most instances, one replicate with 10 test fishes was run for each experiment. The exceptions were the shiner surfperch and English sole bioassays run with the August 29 sample and the English sole bioassay run with the September 6 sample; in these

cases there were two replicates of each concentration, each with 10 fishes. Initially 20 shrimp were tested in each concentration of the shrimp bioassays. However, 10 were used commencing September 16, 1973.

Table 6-4. Percent Survival of Test Organisms After 96 Hours Exposure to Air Activated Sludge Effluent (Southeast WPCP Service Area), 1973

Effluent collection date	Effluent concentration, percent											
	Shiner surfperch				English sole				Bay shrimp			
	0	10	50	100	0	10	50	100	0	10	50	100
Aug. 29	100[a]	100[a]	100[a]	95[a]	100[a]	100[a]	100[a]	100[a]	80[a]	90[a]	90[a]	90[a]
Aug. 31	100	100	100	100	100	100	100	100	-	-	-	-
Sept. 4	100	100	100	100	100	100	90	100	-	-	-	-
Sept. 5	-	-	-	-	100	100	100	100	85[a]	55[a]	70[a]	70[a]
Sept. 6	-	-	-	-	100[a]	95[a]	100[a]	95[a]	-	-	-	-
Sept. 7	-	-	-	-	100	100	100	100	85[a]	80[a]	65[a]	80[a]
Sept. 9	100	100	90	100	90	100	80	100	-	-	-	-
Sept. 10	100	100	100	100	100	100	100	100	-	-	-	-
Sept. 11	90	90	80	90	-	-	-	-	80[a]	70[a]	80[a]	85[a]
Sept. 12	100	100	100	100	90	90	100	100	-	-	-	-
Sept. 14	90	70	60	80	80	100	100	90	-	-	-	-
Sept. 15	80	70	60	70	100	100	100	100	-	-	-	-
Sept. 16	100	100	90	90	-	-	-	-	90	90	90	80
Sept. 17	-	-	-	-	100	100	90	100	-	-	-	-
Sept. 24	100	100	100	100	-	-	-	-	-	-	-	-
Sept. 25	100	100	100	100	90	90	100	100	-	-	-	-
Sept. 26	100	100	100	100	100	100	100	100	-	-	-	-
Mean	96.9	94.6	90.8	94.2	96.4	98.2	97.1	98.9	84.0	77.0	79.0	81.0
Std. dev.	6.3	11.3	15.0	9.5	6.3	3.7	6.1	2.9	4.2	14.8	11.4	7.4

[a]Data are means of two replicates

No apparent toxicity was recorded with any of the three species in these tests. Chi-square analyses of these data indicated no significant differences among the various effluent concentrations (see appendix). The mean survival percentages in undiluted effluent were 94.2, 98.9, and 81.0 percent for shiner surfperch, English sole, and bay shrimp, respectively. The heaviest shiner surfperch mortality occurred in the September 14 and 15 effluent samples, but in both tests the dead fishes as well as some of the live fishes had symptons of caudal fin rot. Mortality in the English sole tests was incidental. Survival was 90 percent or greater on all but two occasions when the percentage dropped to 80 percent, and one of these occurred in the controls. Survival in the bay shrimp bioassays was lower than in either the shiner surfperch or English sole bioassays.

A substantial percentage of the shrimp that died had also shed their carapaces. It was not determined whether or not this molting was natural or stress induced, but it was generally observed that the shrimp died on molting. In the experiments

through September 11, it was also observed that many of the freshly molted shrimp were cannibalized whereas those with hardened carapaces were not. When the shrimp were placed in solitary cages the cannibalization stopped, of course, but it was still noted that most of the shrimp that died had molted. Since mortality could not be associated with effluent concentration, neither could the molting. In the September 24 tests, for example, 11 of the total of 13 mortalities had shed their carapaces. The results of this test are omitted from Table 6-4 because of low survival in the controls (see appendix). Survival in this test was 90 percent in both the 50 and 100 percent effluent concentrations and only 60 and 30 percent in the control and 10 percent concentrations, respectively. From these observations, it seems likely that the molting phenomenon is associated with the handling stresses inherent to the bioassay procedure.

Ferric Chloride Flocculation Effluents. The ferric chloride flocculation effluent samples used in these tests had been filtered through a dual media filter, anthracite and sand, followed by an activated carbon sorption column as part of the pilot plant treatment process. Because of this high degree of treatment, it was expected that the toxicity of the effluents would be relatively low. The results of the tests presented in Table 6-5 generally confirm this expectation.

Table 6-5. Percent Survival of Test Organisms After 96 Hours Exposure to Ferric Chloride Flocculation and Sedimentation Effluent with Activated Carbon Sorption (Southeast WPCP Service Area), 1973

Effluent collection date	Effluent concentrations, percent											
	Shiner surfperch				English sole				Bay shrimp			
	0	10	50	100	0	10	50	100	0	10	50	100
Aug. 30	100[a]	100[a]	100[a]	100[a]	100	100	100	100	95	90	85	70
Aug. 31	100	100	100	100	100	100	100	100	-	-	-	-
Sept. 4	100	100	100	100	100	100	100	100	-	-	-	-
Sept. 5	-	-	-	-	100	100	100	100	-	-	-	-
Sept. 6	-	-	-	-	95[a]	95[a]	100[a]	95[a]	-	-	-	-
Sept. 7	-	-	-	-	100	100	100	70	-	-	-	-
Sept. 9	100	90	100	90	100	80	90	90	-	-	-	-
Sept. 10	100	100	100	100	100	100	100	100	-	-	-	-
Sept. 11	100	90	90	80	-	-	-	-	80	75	80	65
Sept. 12	100	100	100	20	100	90	100	90	-	-	-	-
Sept. 14	-	-	-	-	90	100	100	100	-	-	-	-
Sept. 15	80	100	70	60	100	90	100	100	-	-	-	-
Sept. 16	80	70	70	100	-	-	-	-	90	100	80	80
Sept. 17	-	-	-	-	100	100	100	100	-	-	-	-
Sept. 24	100	100	0[b]	100	-	-	-	-	90	90	50	60
Sept. 25	100	100	100	100	80	100	90	100	-	-	-	-
Sept. 26	100	100	100	100	100	100	100	100	-	-	-	-
Mean	96.7	95.8	93.6	87.5	97.5	96.8	98.6	96.1	88.8	88.8	73.8	68.8
Std. dev.	7.8	9.0	12.1	24.5	5.8	6.1	3.6	8.4	6.3	10.3	16.0	8.5

[a] Data are means of two replicates

[b] Mortality caused by a malfunction in the aeration system. See text for details.

Survivals of shiner surfperch and English sole were generally high in all effluent concentrations, averaging 87.5 and 96.1 percent, respectively, in the undiluted effluents. Chi-square analyses of the data showed no significant differences among the effluent concentrations for either set of experiments; however, significant differences were noted in tests on the September 7 sample with English sole and on the September 12 sample with shiner surfperch (summarized in the appendix). The September 12 sample was notable because only 20 percent of the shiners survived in the undiluted influent. The English sole survival rate was 90 percent in the same sample, and 100 percent survival was obtained with both shiner surfperch and English sole in the September 12 air activated sludge samples. Symptoms of bacterial fin rot were not observed in the September 12 test; however, the disease definitely occurred in the tests on effluents collected September 14, (see appendix for results of this test) 15, and 16. Most of the shiner surfperch that died in the September 14, 15, and 16 effluent tests showed evidence of caudal fin erosion in the control as well as in the effluent dilutions. Caudal fin erosion was observed on the same dates with the air activated sludge tests and probably was the result of inadequate prophylactic treatment of the fishes prior to testing. The 100 percent mortality that occurred in the 50 percent concentration of the September 24 effluent was the result of a malfunction in the aeration system; the dissolved oxygen dropped to less than 1 mg/l in the first 24 hours. Ten extra fishes were added for the duration of the test and 100 percent survival was obtained. As was the case with the air activated sludge effluent tests, mortality among the English sole was incidental. In both sets of tests most of the English sole which died were observed to have reddened snouts, possible from repeated collisions with the sides of the tanks.

Bay shrimp survival averaged slightly higher in the control and 10 percent effluent concentrations than in the 50 and 100 percent concentrations. Chi-square analyses did not detect any significant overall differences in this series of tests. There was also no significant differences detected among the effluent concentrations in individual experiments (summarized in the appendix). The occurrence of shed carapaces was noted, but again there was no association with effluent concentration.

Comparison of the Pilot Plant Effluents from Southeast WPCP. A comparison of the results of the acute toxicity tests run on the air activated sludge and ferric chloride flocculation effluents from the Southeast WPCP shows that the differences in toxicity between the two processes were relatively small. A chi-square analysis did not show any significant differences between the two treatment processes (summarized in the appendix). Survival among the three test species was slightly higher in the undiluted air activated sludge effluents, averaging 94.2, 98.9, and 81.0 percent compared with 87.5, 96.1, and 68.8 percent in the undiluted ferric chloride flocculation effluent for shiner surfperch, English sole and bay shrimp, respectively (see appendix). A chi-square analysis did not show a significant difference between the treatment processes. However, whether or not the differences are significant is probably not as important as the fact that it was necessary to test undiluted effluent to cause mortality, and even then the mortality was generally low.

To provide another baseline for interpretation of these experiments, a series of bioassays using the threespine stickleback accompanied most of the tests. The results of these tests, summarized in Table 6-6, show that the toxicity of these effluents to this species was low. In fact, only two mortalities occurred among all the sticklebacks tested. Sticklebacks are normally used as a test organism for wastewater effluents in the San Francisco Bay area, and therefore provide a familiar reference point.

Acute Toxicity Tests on Pilot Plant Effluents from the North Point-Southeast WPCP Service Areas

A series of 96-hour acute toxicity bioassays was run on treated effluents from a blend of North Point and Southeast WPCP influent feeds. This mixture was apportioned in a three to one ratio, which reflects the relative flows of the two plants. Pilot plant effluents from the air activated sludge and ferric chloride flocculation processes were tested as before, but towards the end of the testing program the only effluent tested was from the ferric chloride flocculation process without filtration and activated carbon sorption.

Table 6-6. Percent Survival of Threespine Stickleback in Pilot Plant Effluent (Southeast WPCP Service Area), 1973

Effluent collection date	Activated sludge effluent concentration, percent			Ferric chloride floc effluent concentration[b], percent		
	0	56	100[a]	0	56	100
Aug. 30	-	-	-	100	100	100
Aug. 31	100	100	100	100	100	100
Sept. 4	100	100	100	100	100	100
Sept. 5	100	100	100	100	100	100
Sept. 6	100	-	100	100	-	95
Sept. 7	100	-	100	100	-	95
Sept. 9	100	-	100	100	-	100
Sept. 10	100	-	100	100	-	100
Sept. 11	100	-	100	100	-	100
Sept. 12	100	-	100	100	-	100
Sept. 14	100	-	100	100	-	100
Sept. 15	100	-	100	100	-	100
Sept. 16	100	-	100	100	-	100
Sept. 17	100	-	100	100	-	100
Sept. 24	100	-	100	100	-	100
Sept. 25	100	-	100	100	-	100
Sept. 26	100	-	100	100	-	100

[a] Data for 100 percent effluent concentrations are means of two replicates.

[b] With activated carbon sorption.

Air Activated Sludge Effluents. The air activated sludge effluents from the North Point-Southeast WPCP wastewater mixture were tested from October 2 through 17, inclusive, as shown in Table 6-7. The survival percentages in 100 percent effluent were high, averaging 100, 95.7, and 83.3 percent for the shiner surfperch, English sole, and bay shrimp, respectively. There was 100 percent survival among the shiner surfperch in the controls and in all effluent dilutions tested. This not only reflects low toxicity, but also the fact that the problems with bacterial fin rot disease had been overcome. The English sole survival averaged greater than 95 percent in the controls and effluent dilutions. Bay shrimp survival in the effluent dilutions averaged slightly higher than that obtained with the Southeast WPCP effluents (Table 6-4). The shedding of carapaces was still evident, but some live shrimp with shed carapaces were also noted. Chi-square analyses were performed on the data from these tests and no significant differences were found (summarized in appendix).

Ferric Chloride Flocculation and Sedimentation Effluents with Activated Carbon Sorption. The tests on ferric chloride flocculation effluents with activated carbon sorption resulted in higher survival averages than those obtained in comparable air activated sludge effluents (Table 6-8). One hundred percent survival was again obtained with shiner surfperch in the controls and in all dilutions. Only three English sole mortalities occurred in the entire series of tests. The bay shrimp survival was uniformly high, averaging 90.0 percent in the controls and 87.5 percent cent in the undiluted effluent. Chi-square analyses, summarized in the appendix, showed no significant affect with any of the test organism.

Table 6-7. Percent Survival of Test Organisms After 96 Hours Exposure to Air Activated Sludge Effluent (North Point-Southeast WPCP Service Area), 1973

Effluent collection date	Effluent concentration, percent											
	Shiner surfperch				English sole				Bay shrimp			
	0	10	50	100	0	10	50	100	0	10	50	100
Oct. 2	100	100	100	100	100	100	100	90	-	-	-	-
Oct. 3	100	100	100	100	100	100	80	90	-	-	-	-
Oct. 4	100	100	100	100	-	-	-	-	80	90	90	90
Oct. 5	100	100	100	100	-	-	-	-	-	-	-	-
Oct. 7	100	100	100	100	-	-	-	-	80	100	100	90
Oct. 8	100	100	100	100	-	-	-	-	-	-	-	-
Oct. 9	100	100	100	100	90	100	100	100	-	-	-	-
Oct. 10	100	100	100	100	100	100	100	100	-	-	-	-
Oct. 12	100	100	100	100	-	-	-	-	90	90	90	70
Oct. 13	100	100	100	100	100	100	90	100	-	-	-	-
Oct. 14	100	100	100	100	-	-	-	-	-	-	-	-
Oct. 15	100	100	100	100	100	100	100	100	-	-	-	-
Oct. 17	100	100	100	100	90	100	100	90	-	-	-	-
Mean	100	100	100	100	97.1	100	95.7	95.7	83.3	93.3	93.3	83.3
Std. dev.	0	0	0	0	4.9	0	7.9	5.3	5.8	5.8	5.8	11.5

Table 6-8. Percent Survival of Test Organisms After 96 Hours Exposure to Ferric Chloride Flocculation and Sedimentation Effluent with Activated Carbon Sorption (North Point-Southeast WPCP Service Area), 1973

Effluent collection date	Effluent concentration, percent											
	Shiner surfperch				English sole				Bay shrimp			
	0	10	50	100	0	10	50	100	0	10	50	100
Oct. 2	100	100	100	100	100	100	100	100	-	-	-	-
Oct. 3	100	100	100	100	90	100	100	90	-	-	-	-
Oct. 4	100	100	100	100	-	-	-	-	100	80	80	90
Oct. 5	100	100	100	100	-	-	-	-	90	70	80	90
Oct. 7	100	100	100	100	-	-	-	-	80	90	70	100
Oct. 8	100	100	100	100	-	-	-	-	90	80	100	70
Oct. 9	100	100	100	100	100	100	100	100	-	-	-	-
Oct. 10	100	100	100	100	100	100	100	100	-	-	-	-
Oct. 12	100	100	100	100	-	-	-	-	-	-	-	-
Oct. 13	100	100	100	100	100	100	100	90	-	-	-	-
Oct. 14	100	100	100	100	-	-	-	-	-	-	-	-
Oct. 15	100	100	100	100	100	100	100	100	-	-	-	-
Oct. 17	100	100	100	100	100	100	100	100	-	-	-	-
Mean	100	100	100	100	98.6	100	100	97.1	90.0	80.0	82.5	87.5
Std. dev.	0	0	0	0	3.8	0	0	4.9	8.2	8.2	12.6	12.6

Ferric Chloride Flocculation and Sedimentation Effluents without Activated Carbon Sorption. Four acute toxicity tests were run on samples of effluent from ferric chloride flocculation and sedimentation effluent without filtration or activated carbon sorption. The results of these tests, shown in Table 6-9, were similar to the results with activated carbon sorption in that the toxicity was low. Average survivals of 92.8 and 99.3 percent were obtained in the shiner surfperch and English sole tests respectively, in undiluted effluent, as compared with 100 percent survival in the control for both species. The shiner surfperch appeared to be under stress when first introduced to the undiluted effluent, but they quickly recovered. Results from the tests on bay shrimp were erratic in both the controls and effluent dilutions. Two experiments were deleted because of low survival percentages in the controls. In the remaining two experiments, survival in the controls averaged 85.0 percent, while survival in 50 and 100 percent effluent concentration averaged 75.0 and 73.5 percent, respectively. However, chi-square analyses again showed that the differences among the effluent concentrations were not statistically significant (summarized in the appendix).

Table 6-9. Percent Survival of Test Organisms After 96 Hours Exposure to Ferric Chloride Flocculation and Sedimentation Effluents without Activated Carbon Sorption (North Point-Southeast WPCP Service Areas), 1973

Effluent collection date	Effluent concentration, percent								
	Shiner surfperch			English sole			Bay shrimp		
	0	50	100[a]	0	50	100[a]	0	50	100[a]
Oct. 18	100	100	97	100	100	100	-	-	-
Oct. 19	100	100	97	100	100	100	-	-	-
Oct. 22	100	100	90	100	100	97	80	80	77
Oct. 24	100	100	87	100	100	100	90	70	70
Mean	100	100	92.8	100	100	99.3	85.0	75.0	73.5
Std. dev.	0	0	5.1	0	0	1.5	7.1	7.1	5.0

[a]Data for 100 percent effluents are means of three replicates

Comparison of Pilot Plant Effluents from the North Point-Southeast WPCP Mixture. The results of this series of bioassays showed that there was no apparent acute toxicity to shiner surfperch, English sole, or bay shrimp with either the air activated sludge or the ferric chloride flocculation and sedimentation pilot plant effluents with filtration and activated carbon sorption. A comparison of the results between the two treatment processes using chi-square analyses showed that the differences were not statistically significant (summarized in the appendix). There was no evidence that the ferric chloride flocculation effluent without activated carbon sorption was toxic under the test conditions, but an initial stress response was observed with the shiner surfperch in undiluted effluent.

The results of the stickleback bioassays that accompanied these tests are summarized in Table 6-10. Virtually no toxicity was measured in either the air activated sludge or ferric chloride effluents with activated carbon sorption. The respective survival averages were 99.2 and 95.6 percent in undiluted effluent.

Survival in undiluted ferric chloride effluent without activated carbon sorption averaged 85.0 percent, which was slightly lower than the survival in the samples with carbon sorption. These results may have been adversely influenced, however, by a heavy infestation of parasitic gill copepods in the batch of fishes used for these tests. As with the Southeast WPCP effluents, no clear-cut toxic response occurred in any of the tests on the North Point-Southeast WPCP wastewater mixture.

Table 6-10. Percent Survival of Threespine Stickleback in Pilot Plant Effluents (North Point-Southeast WPCP Service Areas), 1973

Effluent collection date	Activated sludge effluent concentration, percent		Ferric chloride floc effluent concentration, percent	
	0	100[a]	0	100[a]
Oct. 2	100	100	100	100
Oct. 3	100	100	100	100
Oct. 4	100	100	100	100
Oct. 5	100	100	100	100
Oct. 7	100	100	100	100
Oct. 8	100	100	100	100
Oct. 9	100	95	100	95
Oct. 10	90	95	90	90
Oct. 12	100	100	100	100
Oct. 13	100	100	100	100
Oct. 14	100	100	100	100
Oct. 15	100	100	100	100
Oct. 17	100	100	100	100
Oct. 18[b]	-	-	100	95
Oct. 19	-	-	100	100
Oct. 22	-	-	90	80
Oct. 24	-	-	100	65
Mean	99.2	99.2	98.8	95.6
Std. dev.	2.8	1.9	3.3	9.5

[a] Data for 100 percent effluent concentrations are means of two replicates.
[b] Ferric chloride flocculation and sedimentation effluents without activated carbon sorption from October 18-24 inclusive.

Chronic Toxicity

Two chronic toxicity tests were performed on the pilot plant effluents. The intention was to run 25 day experiments to test the effects of exposure to wastewater effluents over a period longer than 96 hours. Unfortunately the length of the tests was limited by the availability of the effluents and test organisms. The first test was run for 12 days on an effluent which reflected 100 percent Southeast WPCP influent. The second test was run for 23 days using the North Point-Southeast WPCP mixture. In both tests, the activated sludge effluent samples were collected from the secondary sedimentation tanks and the ferric chloride flocculation and sedimentation effluent samples were collected after filtration and activated carbon sorption. The test organisms were English sole and shiner surfperch. Bay shrimp were not tested because it was unlikely that survival in the controls would have been high enough to assess the chronic toxicity of the effluents tested.

Southeast WPCP Effluent. The results of the 12 day chronic toxicity bioassay on pilot plant treated effluents from Southeast WPCP influent feed are shown in Fig. 6-1. The experiment was run with 24 hour composite effluent samples collected from September 15 to 26, 1973, inclusive, and was terminated because the pilot plant influent feed was changed. English sole survival averaged 90 percent in the controls and 100 and 95 percent in the undiluted ferric chloride flocculation and activated sludge effluents, respectively. Survival also averaged 90 percent in the shiner surfperch controls, but survival in the ferric chloride flocculation and activated sludge effluents averaged 45 and 25 percent, respectively.

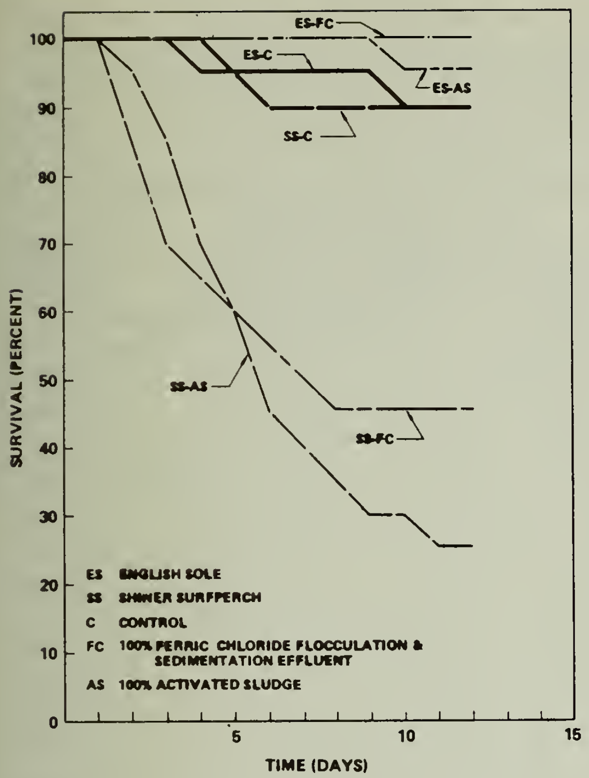


Fig. 6-1. Percent Survival of English Sole and Shiner Surfperch in Undiluted Pilot Plant Effluents (Southeast WPCP Service Area), 12 Day Test Duration, 1973

The low survival of the shiner surfperch was in part attributable to bacterial fin rot disease. Because of the limited time the effluent from the Southeast WPCP was available, shiners which had not completed their prophylactic treatment were used in this test. Nineteen of the 28 shiners that died during the course of the experiment had symptons of bacterial fin rot. Since survival was 90 percent in the controls, exposure to wastewater effluent apparently increased the susceptibility of the fishes to this disease.

North Point-Southeast WPCP Effluent. The results of the 23 day chronic toxicity bioassay on the North Point-Southeast WPCP mixture (Fig. 6-2) show that high survival was obtained with both species of fishes in both pilot plant effluents. Only one shiner surfperch died during the course of the experiment, and that was in undiluted activated sludge effluent. Survival percentages of 85, 80, and 70 percent were obtained with the English sole in the controls, ferric chloride flocculation and sedimentation effluents, and activated sludge effluents, respectively. These averages are lower than were obtained with the pilot plant effluents from the Southeast WPCP service areas. However the results were still relatively high considering the effluent samples were undiluted.

Acute Toxicity Tests on Primary Effluents

A monthly series of acute toxicity tests was run on primary effluent samples from North Point and Southeast WPCP collected upstream and downstream from the respective postchlorination points. The bioassays on samples collected after postchlorination were performed as part of the Self-Monitoring Program required by the San Francisco Bay Regional Water Quality Control Board (RWQCB). In accordance with RWQCB requirements, the tests are run on samples of effluent as it is discharged: that is, with a chlorine residual unless the effluent is normally dechlorinated. Tests were run on effluent samples collected upstream from postchlorination in this study to measure the acute toxicity caused by factors other than chlorine. Tests were run for one year from May, 1973 through April, 1974. No test was run in March, 1974 because a labor dispute resulted in the shutdown of both plants.

Chlorination practices differed between the two plants during the course of this study. At the Southeast WPCP, the sewage is normally prechlorinated for odor control and postchlorinated for disinfection. Because of the prechlorination, a chloramine residual can persist in effluent samples collected prior to postchlorination. This residual may be below the detection limits of the test for chlorine residual. At the North Point WPCP the sewage also undergoes prechlorination for odor control, but personnel at the plant were experimenting with a dechlorination system and varied the postchlorination point. Normally the effluent from the sedimentation tanks is

chlorinated for disinfection; however, an intermediate chlorination point upstream from the sedimentation tanks was used for several months. The result was that a chlorine residual was found in effluent samples collected upstream and downstream from the normal postchlorination point.

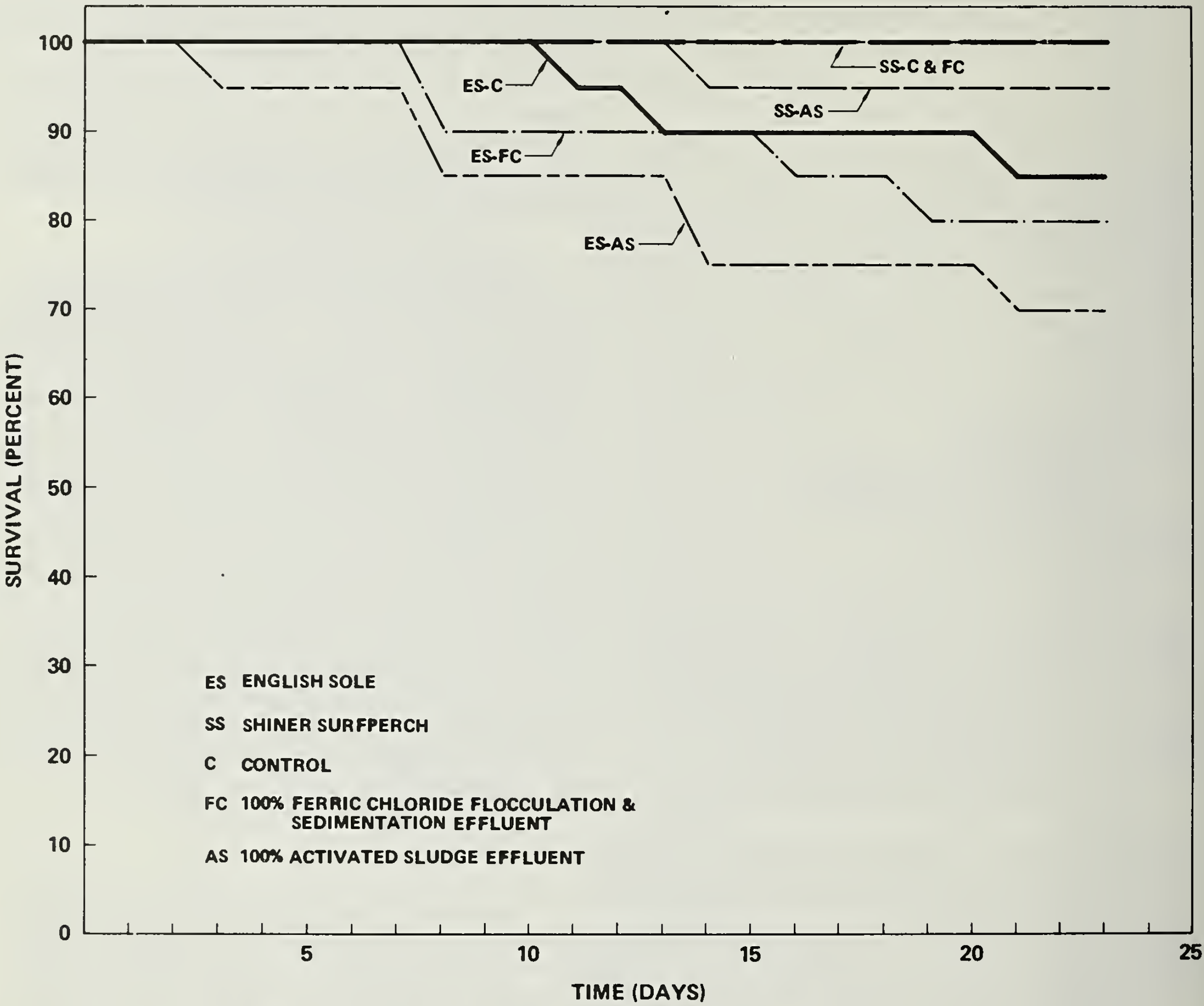


Fig. 6-2. Percent Survival of English Sole and Shiner Surfperch in Undiluted Pilot Plant Effluents (North Point-Southeast WPCP Service Areas), 23 Day Test Duration, 1973

Table 6-11 shows the results of the tests on the North Point WPCP effluents. The percent survival in undiluted effluent was closely correlated with measured chlorine residual. Also the survival percentage for each test was similar for both the 24 and 96 hour exposure times. Since the effects of chlorine occur within 24 hours, this is further evidence of chlorine toxicity. Relatively high survival percentages were obtained in effluent samples collected upstream of the post-chlorination point. Most of the 96 hour TL_m values for these samples were greater than 100 percent. On several of these samples (including those collected November 26 and December 18, 1973 and February 20, 1974), chlorine had been added upstream from the sedimentation tanks for disinfection. This resulted in markedly lower survival percentages in the acute toxicity tests. Survival in the post-chlorinated samples also tended to be lower when chlorine was added upstream from the sedimentation tanks.

Table 6-11. Acute Toxicity Tests on Primary Effluents from North Point WPCP Using Threespine Sticklebacks, 1973-74

Sample collection date	Prior to postchlorination point				After postchlorination point			
	Percent survival in undiluted effluent		96-hour TL_m, percent	Chlorine residual, mg/l	Percent survival in undiluted effluent		96-hour TL_m, percent	Chlorine residual, mg/l
	24-hours	96-hours			24-hours	96-hours		
May 8	100	100	>100	<0.1	80	70	>100	1.1
June 12	70	70	>100	<0.1	100	90	>100	1.1
July 17	100	100	>100	<0.1	100	100	>100	<0.1
Aug 6	100	60	>100	<0.1	80	70	>100	<0.1
Sept 19	100	100	>100	<0.1	0	0	75	0.8
Oct 10	100	90	>100	<0.1	100	100	>100	<0.1
Nov 26	30	10	77	0.9	0	0	70	1.6
Dec 18	0	0	40	3.3	0	0	38	3.4
Jan 22	100	90	>100	<0.1	0	0	48	5.6
Feb 20	0	0	73	2.5	0	0	42	2.6
Apr 15	100	70	>100	<0.1	100	60	>100	0.5

Table 6-12 shows the results of the tests on primary effluents from the Southeast WPCP. A few fishes survived 24 hours in undiluted effluent collected downstream of the postchlorination point, but all were dead at 96 hours. The 96 hour TL_m values for these tests ranged from 13 to 75 percent. The lowest TL_m values, 13 and 26 percent, are associated with measured chlorine residuals of 5.0 and 3.8 mg/l, respectively. The survival in effluent samples collected upstream of the postchlorination point ranged from 0 to 70 percent; only three of the 11 tests performed resulted in 96 hour survivals of 50 percent or greater. The 96 hour TL_m values for these tests ranged from 40 to 100 percent or greater. The values were generally higher than comparable TL_m values from samples collected downstream from postchlorination.

Overall, it is apparent that much of the acute toxicity in effluent samples from both the North Point and Southeast plants can be attributed to chlorine residuals. Survival in the North Point WPCP samples was very closely related to the measured chlorine residuals. Survival in the Southeast WPCP samples also was reduced when high chlorine residuals were found. The low survivals in many of the Southeast WPCP samples collected upstream of the postchlorination point may have been caused by other toxicants, but the possibility of toxicity also from chloramine residuals cannot be eliminated because of the prechlorination for odor control.

Table 6-12. Acute Toxicity Tests on Primary Effluents from Southeast WPCP Using Threespine Sticklebacks, 1973-74

Sample collection date	Prior to postchlorination point				After postchlorination point			
	Percent survival in undiluted effluent		96-hour TL_m, percent	Chlorine residual mg/l	Percent survival in undiluted effluent		96-hour TL_m, percent	Chlorine residual mg/l
	24-hours	96-hours			24-hours	96-hours		
May 9	100	60	>100	<0.1	0	0	75	4.4
June 14	60	20	40	<0.1	0	0	72	4.1
July 24	80	0	70	<0.1	20	0	70	0.8
Aug 7	100	0	75	<0.1	30	0	72	0.6
Sept 12	0	0	75	<0.1	30	0	75	1.4
Oct 25	0	0	75	<0.1	10	0	73	1.4
Nov 27	100	10	77	<0.1	0	0	56	2.3
Dec 12	100	50	100	<0.1	0	0	13	5.0
Jan 30	100	0	75	<0.1	10	0	75	1.7
Feb 22	90	0	75	<0.1	0	0	26	3.8
Apr 19	100	70	>100	<0.1	0	0	41	1.9

RESULTS OF THE TOXICITY STUDIES ON DUNGENESS CRABS

This section presents the results of the bioassay tests of the effects of pilot plant effluents on the immature stages of Dungeness crabs. The egg hatching experiments, acute toxicity experiments, and chronic toxicity experiments are discussed.

Results of Egg Hatching Experiments

Four experiments were performed to test the effects of pilot plant effluents on the hatching success of Dungeness crab eggs. Each experiment reflected exposure of eggs from a different crab to different effluent samples. Sixteen conditions were tested including the effects of background waters, salinity, and wastewater concentrations from two treatment processes ranging from one to 50 percent. The collection dates for the effluent samples were December 31, 1973 to January 3, 1974; January 26-29, 1974; January 21-25, 1974; and January 24-27, 1974 for experiments E-H, H-H, L-H, and M-H, respectively. The results of three of these experiments are discussed in the following sections. The fourth experiment, L-H, was not valid because of the low survival rate in the controls.

The natural variability among test organisms as well as the testing procedures must be evaluated before any assessment of the effects of the pilot plant effluents can be made. Table 6-13 summarizes the responses of the eggs in the Steinhart and synthetic seawater controls for all four experiments. A slightly higher percentage of the eggs in the synthetic seawater controls resulted in first stage zoeae than in the Steinhart seawater controls. Variation among the replicates within each experiment was low for both background waters. The standard deviations for these replicates ranged from 2.1 to 7.7 percent. The variation among experiments, however, was very high and an analysis of variance, (summarized in the appendix) showed that these differences were statistically significant at the 99.9 percent confidence level. Most of the variation among experiments was attributable to the

deviation of experiment L-H. Many of the eggs in that experiment either did not hatch or hatched into prezoeae which did not molt into first stage zoeae within the 96 hour test period. The large differences between the results of experiment L-H and experiments E-H, H-H, and M-H show that biological variability can be a major factor in data interpretation. Since satisfactory results were not obtained in the controls, the results of experiment L-H were not considered in subsequent analyses.

Table 6-13. Percentage[a] of Prezoeae and Zoeae Obtained from Dungeness Crab Eggs Exposed to Steinhart and Synthetic Seawater for 96 Hours Exposure, Mean and Standard Deviation, 1974

	Steinhart seawater		Synthetic seawater	
Experiment	Prezoeae	Zoeae	Prezoeae	Zoeae
E-H	3.3 ± 2.8	93.2 ± 2.9	1.6 ± 2.7	96.6 ± 2.9
H-H	3.4 ± 3.0	95.0 ± 5.0	3.5 ± 3.0	96.7 ± 2.9
L-H	13.8 ± 2.8	72.5 ± 2.1	6.7 ± 7.6	80.0 ± 5.0
M-H	1.6 ± 2.7	91.7 ± 2.9	3.4 ± 3.0	91.5 ± 7.7

[a]Data are means of three replicates. The remainder are eggs that did not hatch within the 96-hour test period.

Effect of Dilution Waters in the Egg Hatching Experiments. Steinhart seawater was used as a background water in the egg hatching experiments to simulate natural environmental conditions as closely as possible. However, the use of synthetic seawater was necessitated when 50 percent concentrations of wastewater effluents were tested, to maintain constant salinity levels. Therefore, it is important to have some estimate of the relative effects of the background waters on the test results.

The data in Table 6-13 show that the two background waters had little effect on the percentage of prezoeae or zoeae obtained when wastewater was not added. The background waters were also tested with 10 percent concentrations of both pilot plant effluents to determine if the addition of wastewater affected the results. Each effluent sample was tested with three combinations of background waters: Steinhart seawater, synthetic seawater, and Steinhart seawater with synthetic seawater added. The effluent-Steinhart combination was run at a salinity approximately 10 percent lower than that of the Steinhart control. The other effluent-background water combinations were adjusted to a salinity of 25 ppt. Table 6-14 shows the mean and standard deviation of the percentage of prezoeae and zoeae observed at the end of a 96 hour exposure for each effluent-background water combination. The mean percentages of zoeae ranged from 87.7 to 95.0 and the mean percentages of prezoeae ranged from 1.8 to 8.2. Slightly higher percentages of zoeae were obtained in the effluent-Steinhart seawater combinations than in the effluent-synthetic seawater combinations. This is the converse of the results in the controls in which higher percentages of zoeae were obtained in synthetic seawater. The data in Tables 6-13 and 6-14 indicate that interchanging Steinhart seawater and synthetic seawater as controls or as dilution waters did not significantly affect the results (see analysis of variance tables in the appendix).

Table 6-14. Percentage[a] of Prezoeae and Zoeae Obtained from Dungeness Crab Eggs Exposed to Different Background Waters with Ten Percent Pilot Plant Effluents After 96 Hours Exposure, Experiment E-H, Mean and Standard Deviation

Effluent	Steinhart seawater		Synthetic seawater		Steinhart and Synthetic seawater	
	Prezoeae	Zoeae	Prezoeae	Zoeae	Prezoeae	Zoeae
Air activated sludge	3.4 ± 3.0	95.0 ± 5.0	1.8 ± 3.0	93.3 ± 7.6	8.2 ± 2.8	91.9 ± 2.9
Ferric chloride flocculation	3.7 ± 3.2	93.4 ± 3.0	6.7 ± 2.9	91.7 ± 2.9	9.1 ±12.0	87.7 ± 8.3

[a]Data are means of three replicates.

Salinity Effects in Egg Hatching Experiments. Salinity controls were included in the experiments as a precautionary measure so that the experimental design could be altered if salinity proved to be an important factor at the levels tested. As discussed previously, there was a ten percent difference in salinity among the effluent-dilution water combinations summarized in Table 6-14. Since the differences among the results were not statistically significant, it follows that the 10 percent salinity reduction did not affect egg hatching in these experiments.

Effects of Pilot Plant Effluents on Hatching Success. Table 6-15 shows the percentage of eggs, prezoeae, and zoeae observed at the end of 96 hours exposure to various concentrations of air activated sludge and ferric chloride flocculation pilot plant effluents. Relatively high percentages of first stage zoeae were obtained at all concentrations of the air activated sludge effluents in all three experiments. The analyses of variance (summarized in the appendix) showed no significant differences among the various effluent concentrations. In the ferric chloride effluent, the percentage of zoeae obtained was markedly lower. The percentages of zoeae obtained in the 50 percent concentrations were lower than in the controls in all three experiments, and some effect was noted in concentrations as low as five percent effluent in experiments H-H and M-H. An analysis of variance showed the concentration effects were highly significant, but there was also a highly significant difference among experiments. This is indicative of variable effluent quality and sensitivity among the eggs.

The data in Table 6-15 show that the percentage of prezoeae remaining after a 96 hour exposure was not high except in the 50 percent concentrations of ferric chloride effluent. The range of prezoeae remaining was from 1.6 to 3.4 percent in the controls compared with 1.6 to 10.3 percent in the air activated sludge effluents and 0 to 36.7 percent in the ferric chloride flocculation effluents. The percentages of unhatched eggs remaining ranged from 1.6 to 6.7 percent in the controls, 0 to 6.7 percent in the activated sludge effluents, and 0 to 20.0 percent in the ferric chloride flocculation effluents.

Table 6-15. Percentages of Eggs, Prezoeae and Zoeae Obtained from Dungeness Crab Eggs Exposed to Various Concentrations of Pilot Plant Effluents (Southeast WPCP Service Area) After 96 Hours Exposure, 1973-1974

Experiment	Steinhart Control	Percent activated sludge effluent				Percent ferric chloride effluent			
		1	5	10	50	1	5	10	50
	Mean percentage of eggs remaining								
E-H	3.4	1.6	0	1.7	1.6	3.4	0	3.2	3.2
H-H	1.6	1.6	3.3	3.4	6.7	5.0	1.6	0	5.0
M-H	6.7	3.4	6.6	6.7	1.7	3.3	5.0	6.8	20.0
	Mean percentage prezoeae remaining								
E-H	3.3	5.1	1.6	3.3	8.2	10.2	0	3.5	14.0
H-H	3.4	1.7	6.7	3.3	6.7	1.7	11.7	11.7	30.0
M-H	1.6	8.3	1.7	10.3	6.8	5.0	16.7	18.5	36.7
	Mean percentage zoeae obtained								
E-H	93.3	93.3	98.4	95.0	90.2	86.4	100.0	93.2	82.8
H-H	95.0	96.7	90.0	93.3	86.7	93.3	86.7	88.3	65.0
M-H	91.7	88.3	91.7	83.0	91.5	91.7	78.3	74.7	43.3

Many of the prezoeae remaining after 96 hours were not dead. Therefore, it is possible that some of these would have molted to first stage zoeae after the 96 hours. Also, not all the unhatched eggs were dead, and some would have been expected to hatch were the experiments continued beyond 96 hours. Since not all eggs hatch in nature, it was not expected that all eggs would hatch in the experiment. Eggs which appeared viable were selected for the experiments, but there is no absolute method of predicting whether or not any egg will hatch.

Acute Toxicity of Pilot Plant Effluents to Dungeness Crab Zoeae

A total of fourteen 96 hour acute toxicity experiments were performed using one-day-old first stage zoeae. The zoeae were tested in two pilot plant effluents, activated sludge and ferric chloride flocculation effluents without activated carbon sorption and also in the present primary effluent from the Southeast WPCP. Twelve experiments tested the effects of the pilot plant effluents when salinity was adjusted to a constant of approximately 25 ppt, and two experiments tested the effects of the effluents at a salinity adjusted to approximately 12 ppt. The present primary effluent was tested in four experiments, two at each salinity level. Synthetic seawater was used as the control and dilution water in all experiments.

The 96 hour results of the nine experiments with satisfactory survival in the controls at 25 ppt salinity are summarized in Table 6-16. The experiments in Table 6-16 are listed in chronological order and are designated according to the parent crab and number of experiments performed with zoeae from each crab. The data are expressed as the mean percent survival of three replicates, and the mean and standard deviation are shown for each of the various test conditions.

Table 6-16. Survival of First Stage Zoeae in Pilot Plant Effluents (Southeast WPCP Service Area) After 96 Hours Exposure, 1974

Experiment	Effluent collection dates inclusive, 1974	Mean percent survival [a]						
		Synthetic seawater control	Activated sludge effluent concentration, percent			Ferric chloride flocculation and sedimentation effluent concentration, percent		
			10	20	50	10	20	50
E-1	Jan. 1-4	100.0	90.3	96.7	93.3	93.3	90.0	48.9
E-2	Jan. 3-6	96.7	93.3	93.0	96.7	97.0	83.3	86.7
C-1	Jan. 4-7	88.6	93.3	76.7	83.3	76.7	90.0	26.7
F-1	Jan. 8-11	90.0	96.7	100.0	93.3	100.0	96.7	0.0
F-2	Jan. 8-11	86.7	100.0	90.0	93.3	100.0	90.0	3.3
F-3	Jan. 10-13	90.0	83.3	83.3	93.3	73.3	76.7	13.3
G-1	Jan. 20-23	96.7	100.0	93.3	93.3	100.0	93.3	6.7
N-1	Jan. 28-31	93.3	96.7	86.7	86.7	100.0	80.0	83.3
R-1	Feb. 20-24	86.7	90.0	90.0	90.0	70.0	90.0	20.0
Mean		92.1	93.7	90.0	91.5	90.0	87.8	32.1
Standard deviation		4.8	5.4	7.0	4.1	12.8	6.5	33.4

[a]Data are means of the percentage survival in three replicates

Salinity adjusted to approximately 25 parts per thousand for all test conditions

An attempt was made to evaluate variation among experiments using zoeae from the same crab. Two tests were run with eggs from Crab E, experiments E-1 and E-2, and three tests with zoeae from Crab F, experiments F-1, F-2, and F-3. Using the data in Table 6-16, these tests can be compared among themselves. It is evident that there were variations among the experiments with zoeae from the same source. The survival percentages were comparable in the controls and all effluent concentrations except the 50 percent concentrations of ferric chloride in experiments E-1 and E-2. The respective survival averages were 48.9 and 86.7 percent. There was even close agreement between corresponding results in experiments F-1 and F-2, both in the controls and in all the effluent dilutions. These two experiments were run concurrently with the same effluents so that the only known difference between the two experiments was that different batches of zoeae were used. These results suggest that although zoeae may differ from crab to crab in their responses, siblings can show a relatively high degree of consistency in their responses when exposed to the same effluent samples. In experiment F-3, zoeae from the same crab were again used, but with different effluent samples. The results were slightly different than corresponding values in experiments F-1 and F-2, especially in the ferric chloride effluent.

Effects of Activated Sludge Effluents. Effluent from the activated sludge process was tested at three concentrations, 10, 20, and 50 percent, each of which was adjusted to a salinity of approximately 25 ppt with synthetic seawater. The mean survival percentages representing nine experiments with three replicates for each condition,

were 93.7, 90.0, and 91.5 percent, respectively, as compared with the average survival of 92.1 percent in the controls. No significant differences were detected among the concentrations by an analysis of variance test (see appendix). The lowest survival percentage was 76.7 percent which occurred in the 20 percent concentration of experiment C-1; 83.3 percent survival was obtained in the 50 percent effluent concentration in that experiment. It should be noted, however, that many of the zoeae showed signs of an adverse effect at the 50 percent concentration in several experiments. These effects encompassed a range of symptoms from a reduction in swimming activity to a cessation of all movements except signs of a pulse. The 96 hour EC_{50} concentrations for both reduced swimming activity and death are shown in Table 6-17. The EC_{50} is the effective concentration at which a particular effect occurs in 50 percent of the test organisms as discussed in the data analysis section. In all but two experiments, less than 50 percent of the zoeae exhibited any adverse response. In experiments E-1 and C-1, the respective EC_{50} values were 40 and 34 percent.

Table 6-17. 96-Hour EC_{50} Concentrations for Reduced Swimming Activity and Death of First Stage Zoeae in Pilot Plant Effluents (Southeast WPCP Service Area), 1973-1974

Experiment	EC_{50}[a] concentration, percent			
	Activated sludge effluent		Ferric chloride flocculation and sedimentation effluent	
	Reduced swimming	Death	Reduced swimming	Death
E-1	40	>50	26	49
E-2	>50	>50	28	>50
C-1	34	>50	26	35
F-1	>50	>50	31	31
F-2	>50	>50	30	30
F-3	>50	>50	<10	29
G-1	>50	>50	26	32
N-1	>50	>50	28	>50
R-1	>50	>50	21	34

[a]The EC_{50} concentration is the effective concentration at which a particular response occurs in 50 percent of the test organisms.

Effects of Ferric Chloride Flocculation Effluent. Ferric chloride flocculation effluents were tested in the same manner as the activated sludge effluents. The results, summarized in Table 6-16, show that there was a definite toxic effect at the 50 percent concentration which was statistically significant (see appendix), but at 20 percent effluent concentrations no toxicity was evident. Survival in 50 percent effluent was variable, ranging from zero in experiment F-1 to a high of 86.7 percent in experiment E-2. However, most of this apparent variability can be explained by reference to the EC_{50} concentrations for reduced swimming activity listed in Table 6-17. It can be seen that the EC_{50} concentrations ranged from 21 to 31 percent except in experiment F-3 where the EC_{50} was less than 10 percent. The relatively low EC_{50} concentrations for the ferric chloride flocculation effluents suggest that most of the 96 hour survivors would have expired had the experiment been continued. This possibility is explored further when the results of the chronic tests are presented.

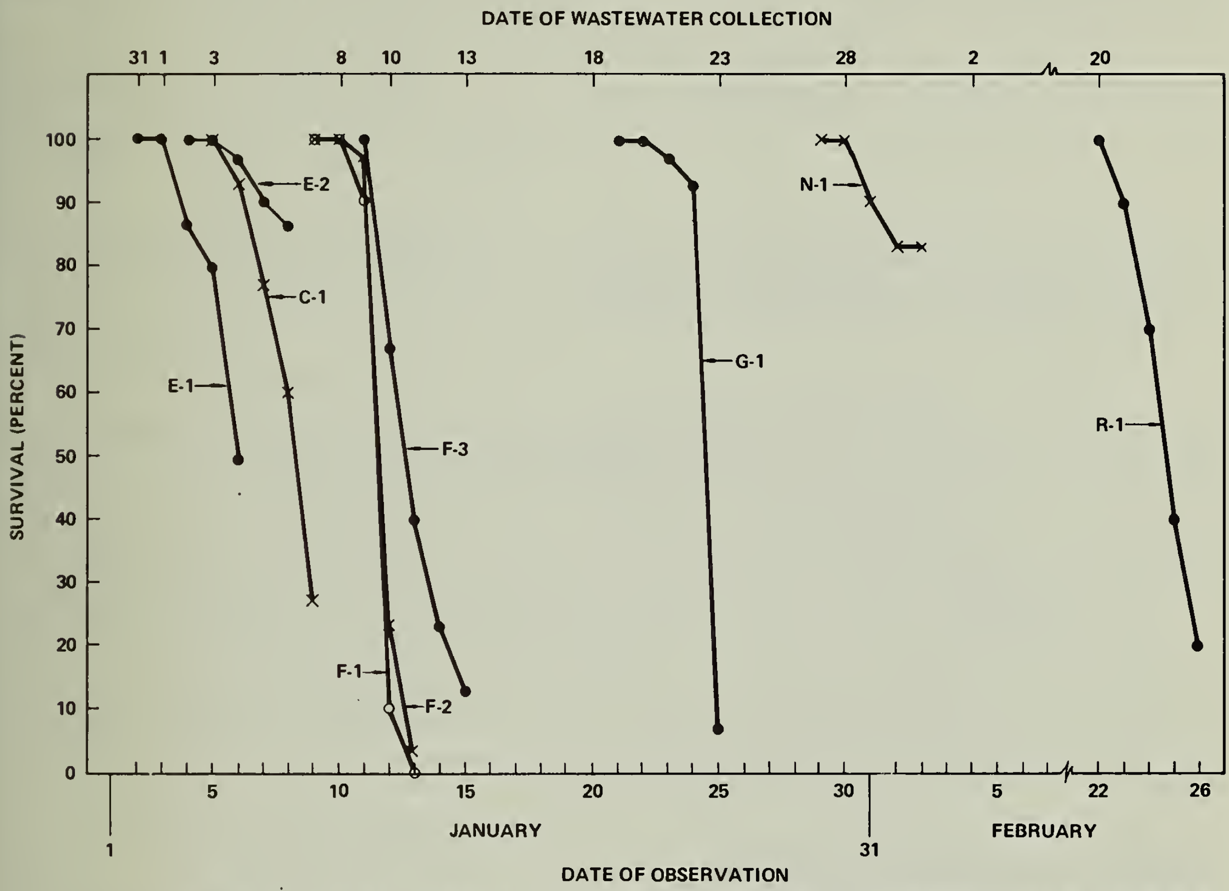
Some of the variability in the results may have been caused by variable effluent quality. This is shown in Fig. 6-3 where the survival in 50 percent ferric chloride flocculation and sedimentation effluent is plotted for the 96 hour test periods. The dates when the collection of the 24 hour composited effluent samples were begun are shown at the top, and the corresponding observation dates which reflect 24 hours of exposure are shown at the bottom. Experiments E-2 and N-1 resulted in little mortality, and experiments E-1, C-1, and R-1 exhibited a gradual decline. On several occasions, rather precipitous declines were observed. On January 12, heavy mortality was recorded in experiments F-1, F-2, and F-3; all survivors were adversely affected. This observation date corresponds to the wastewater sample collected January 10. As will be seen in the section on chronic bioassays, heavy mortality was also recorded in the chronic experiment on this date.

Comparison of Treatment Processes. A comparison was made of the 96 hour acute toxicity of the two pilot plant treatment processes using an analysis of variance test. The results show that there was a highly significant effect of increasing toxicity with increasing effluent concentration, and that there was also a highly significant difference between the toxicity of the effluents from the two treatment processes. The highly significant interaction indicated that the zoeae were not affected the same way by both processes. This is evidenced by the low survival of 32.1 percent in the 50 percent ferric chloride flocculation effluent as compared with 91.5 percent survival in the 50 percent activated sludge effluents.

Effects of Reduced Salinity. The effects of reduced salinity on the toxicity of the two pilot plant effluents were tested in two experiments. The nine experiments reported in the preceding section were adjusted to approximately 25 ppt salinity, corresponding to the ambient salinity of Steinhart seawater. The two experiments reported in this section were salinity adjusted to approximately 12 ppt in all dilutions of wastewater tested.

These experiments (Table 6-18) show that there was no adverse effect from the reduced salinity in the controls, but that there was an effect in the effluent concentrations tested. Although the effects in the air activated sludge effluents were relatively subtle, a chi-square analysis detected no significant differences (see appendix). Most zoeae in the 50 percent concentrations in experiments P-1 and R-1 with 12 ppt salinity exhibited reduced swimming activity, whereas only about half were similarly affected in 50 percent effluent at the higher salinity in experiment R-1. In the ferric chloride flocculation effluent, the effects were

statistically significant (see appendix). At the 50 percent effluent concentration there was 100 percent mortality within 48 hours in experiment P-1 and within 24 hours in experiment R-1. The survival in 20 percent effluent averaged 36.7 and 43.8 percent in experiments P-1 and R-1, respectively, as compared with an average of 93.3 percent at the higher salinity. Decreasing the salinity in the controls had no observed effect after 96 hours exposure, but when wastewater was added, lowering the salinity increased mortality.



Letter-number designations refer to the experiments listed in Table 6-2. Each point represents the mean percentage survival of three replicates, each of which initially contained ten zoeae. The collection dates are the beginning of the 24-hour collection period, and the corresponding observation dates, reflecting 24 hours of exposure, are two days later.

Fig. 6-3. Percent Survival of First Stage Zoeae in 50 Percent Ferric Chloride Flocculation and Sedimentation Effluent (Southeast WPCP Service Area), 1973-1974

Effects of Primary Effluent. The primary effluent from the Southeast WPCP was tested in two experiments (Table 6-19). The testing of primary effluents was not included in the original scope of work, but these effluents were included as part of experiments on pilot plant effluents to obtain comparative data. The salinity was reduced to 12 ppt in experiment P-1, and survival dropped to zero at the 10 percent effluent concentration. In experiment R-1 primary effluent was tested in concentrations up to 50 percent and at salinities of 25 and 12 ppt. At the higher salinity, survival averaged 96.7 percent at the 10 percent effluent concentration and 3.3 percent at the 20 percent effluent concentration. With the salinity at 12 ppt, survival was only 40 percent at the 10 percent effluent concentration. Too few experiments were performed on primary effluents to draw definite conclusions, but

the results indicate a 96 hour TL_m between the 10 and 20 percent effluent concentrations with salinity adjusted to 25 ppt and a TL_m between the five and 10 percent effluent concentrations when the salinity is adjusted to 12 ppt.

Table 6-18. Effects of Reduced Salinity on the Toxicity of Two Pilot Plant Effluents (Southeast WPCP Service Area), 1974

Experiment	Synthetic seawater control	Mean survival after 96 hour exposure, percent [a, b]					
		Activated sludge effluent concentration, percent			Ferric chloride flocculation and sedimentation effluent concentration, percent		
		10	20	50	10	20	50
P-1	100.0	96.7	93.3	90.0	80.0	36.7	0.0
R-1	93.3	96.7	93.3	73.3	90.0	46.7	0.0

[a] Data are expressed as the mean percent of three replicates.

[b] Salinity adjusted to approximately 12 ppt for all test conditions.

Table 6-19. Acute Toxicity of Primary Effluent from Southeast WPCP to First Stage Zoeae, 1974

Experiment	Mean survival after 96-hour exposure, percent[a, b]											
	Concentration of primary effluent at 25 ppt salinity, percent						Concentration of primary effluent at 12 ppt salinity, percent					
	Control	1	5	10	20	50	Control	1	5	10	20	50
P-1	-	-	-	-	-	-	100.0	93.3	96.7	0	-	-
R-1	86.7	86.7	83.3	96.7	3.3	0	93.3	73.3	80.0	40.0	0	0

[a]Data are the mean percent survival of three replicates.

[b]Synthetic seawater was used as the control and dilution water.

Results of the Chronic Bioassays

Two chronic bioassays were performed and the results of both tests showed that the ferric chloride flocculation and sedimentation effluent (without filtration and activated carbon sorption) was more toxic than the activated sludge effluent. The first experiment, labeled E-C, was run for 25 days from January 3 through January 28, 1974. The second experiment, labeled R-C, was run for 15 days from February 22 through March 9, 1974. The results of these experiments are summarized in Table 6-20, which shows the mean percent survival at each effluent concentration for each condition tested.

Controls. In experiment E-C, survival in Steinhart seawater controls was 79.3 percent after 25 days. Most of the mortality occurred within the first ten days, and leveled off thereafter. The first stage zoeae gradually became encumbered with colonizing bacterial filaments which may have contributed to their mortality. In spite of this, most zoeae were active swimmers and feeders. The zoeae began molting to the second stage on day 16, and by day 25 all surviving zoeae had completed the molt. The zoeae were relatively free of the bacterial infestation immediately after molting, since the bacteria were shed with the carapace. Gradually, however, the second stage zoeae also became infested with bacteria, but these zoeae did not appear hindered by the growths.

Table 6-20. Summary of Chronic Toxicity Bioassay Results Using First Stage Zoeae in Pilot Plant Effluents (Southeast WPCP Service Area), 1973-1974

Experiment	Days	Control[a]	Mean survival, percent					
			Concentration of activated sludge effluent, percent			Concentration of ferric chloride flocculation and sedimentation effluent		
			1	5	10	1	5	10
E-C	25	76.7	80.0	73.3	72.2	86.3	21.1	0
. R-C	15	80.0	90.0	86.7	83.3	91.5	70.7	43.3

[a]Steinhart was used as the control and dilution water.

The controls in experiment R-C fared approximately the same as those in the previous experiment. Again most of the mortality occurred within the first ten days. The first stage zoeae gradually became encumbered with bacteria which would have been shed at the second molt. The experiment was terminated before the second molt.

Effects of Pilot Plant Effluents. The pilot plant effluents diluted with Steinhart seawater were tested at concentrations of one, five, and ten percent in experiments E-C and R-C. . The results in Table 6-20 show that in both experiments, the ferric chloride flocculation and sedimentation effluent was more toxic than the activated sludge effluent. At the one percent concentration, neither effluent had any apparent adverse effects. The 25 day survival percentages were 80.0 in activated sludge effluent for experiment E-C and 90.0 percent after 15 days in experiment R-C. The corresponding percentages for the ferric chloride flocculation effluent were 86.3 and 91.5, respectively. All of these values exceeded the survival in the controls which were 79.3 percent in E-C and 76.7 percent in R-C. The addition of small amounts of effluent may have presented a more favorable medium than the filtered Steinhart Aquarium seawater used for the control.

Toxic effects became evident at the five percent concentration using the ferric chloride flocculation effluent, but not with the activated sludge effluent. In experiment E-C, an average of only 21.1 percent survived after 25 days in ferric chloride flocculation effluent, although an average of 70.1 percent survived after 15 days in experiment R-C. In the activated sludge effluent at both five and ten percent concentrations, survival was comparable to that obtained in the controls. Chi-square analyses showed a significant effect in the ferric chloride effluent, but not in the activated sludge effluent (see appendix).

The results of the chronic toxicity bioassays may reflect acute as well as chronic toxicity. Figures 6-4 and 6-5 show the average percent survival plotted against time for experiments E-C and R-C, respectively. A precipitous decline in five and ten percent ferric chloride flocculation effluent is evident in experiment E-C, but in experiment R-C this decline is more gradual at both effluent concentrations. A possible explanation is that the effluent was particularly toxic on one day. In experiment R-C an average of 43.3 percent of the zoeae were recorded as dead on day 9, which was January 12, 1974. Since the medium was changed daily, this observation date reflects 24 hours exposure to wastewater collected on January 10, 1974. Massive mortality and adverse effects were also recorded on January 12, 1974 in acute toxicity experiments F-1, F-2, and F-3 (Fig. 6-3), again reflecting

24 hours exposure to effluent collected January 10, 1974. However, the 96 hour average survival in 10 percent ferric chloride flocculation effluent for experiments F-1, F-2, and F-3 was 100, 100, and 73.3 percent, respectively, and the corresponding values for 20 percent effluent were 96.7, 90.0, and 76.7 percent. Thus, the zoeae died in 10 percent effluent in the chronic experiment, but not in 10 or 20 percent effluent in the acute toxicity experiments. Most likely there was some preconditioning factor, that is, eight to ten days previous exposure which caused the mortality in the chronic bioassay. Conversely, the gradual die-off in experiment R-C (Fig. 6-5) exemplifies what would be expected of chronic toxicity.

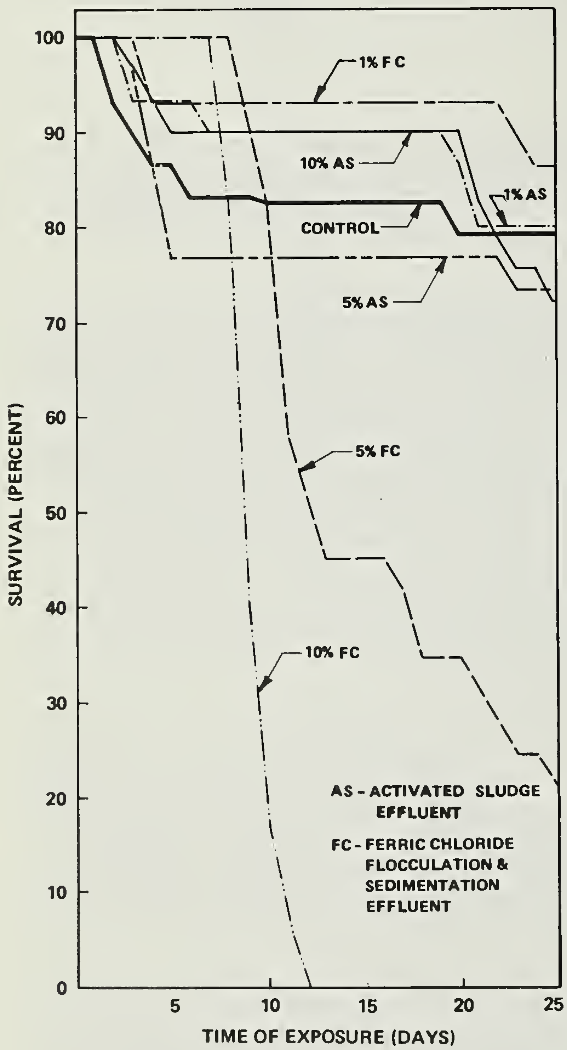


Fig. 6-4. 25-Day Chronic Toxicity Bioassay Experiment E-C Using First Stage Zoeae in Pilot Plant Effluents (Southeast WPCP Service Area), 1973

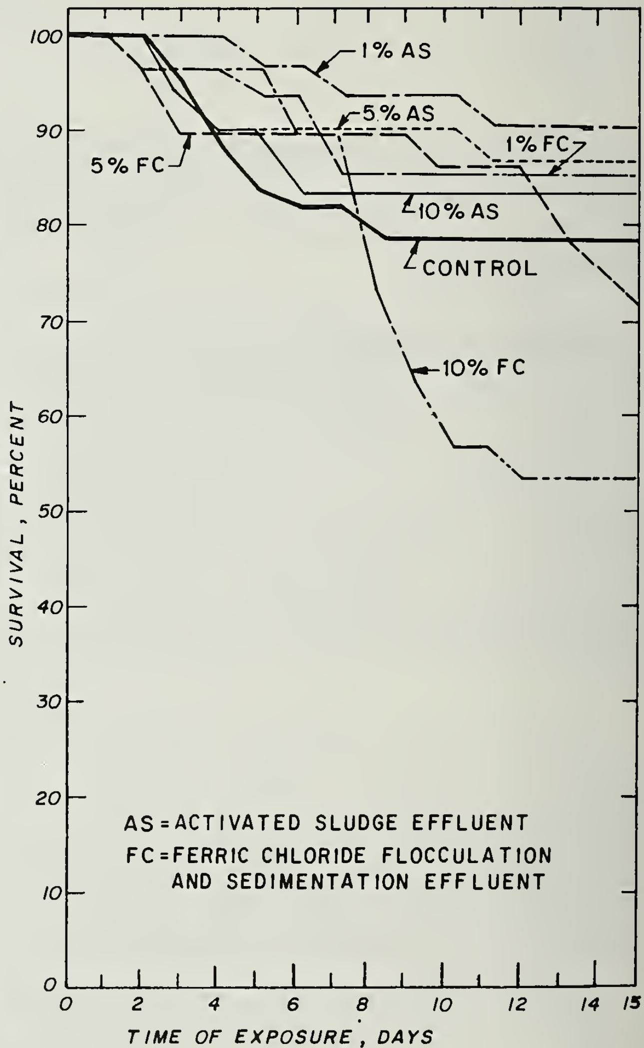


Fig. 6-5. 15-Day Chronic Toxicity Bioassay Experiment R-C with Pilot Plant Effluents (Southeast WPCP Service Area), 1974

One important observation was that mortality was generally not coincidental with molting periods. Molting from the first to second stage zoeae occurred mostly between the fifteenth and twentieth day of exposure. Most of the zoeae that died after day 20 in experiment E-C were second stage so there was no apparent inhibition of the molting process. With the exception of the 5 and 10 percent concentrations of ferric chloride flocculation effluent, it is difficult to distinguish among the results of the effluents or the controls.

Another observation that may be important concerns the external condition of the dead zoeae. The zoeae gradually acquired heavy growths of colonizing bacteria in the controls as well as in the replicates containing wastewater effluent. The bacterial buildup continued until molting and then started over as discussed in the previous section on the controls. The zoeae in the higher concentrations of ferric chloride flocculation effluent were generally more encumbered with bacteria than those in other test conditions. It was observed that the effluent samples often contained quantities of ferric hydroxide floc which may have added to the encumbrance of test organisms when it settled out. This was also evident in the higher concentrations of ferric chloride flocculation effluent in the acute toxicity experiments.

TOXICITY OF WET WEATHER WASTEWATER

In December 1972 the City began a program of routine monitoring of untreated wastewater during periods of wet weather overflow from the combined sewer system to the ocean and bay. Samples are collected at points of overflow throughout the city. Collection normally is within one-half hour of the beginning of an overflow occurrence and hence the samples include the sewer flushing effect of the initial wet weather flow. In the period December 1972 to July 15, 1975, 190 samples were collected for chemical and biological examination. Results of the tests are on file at the Department of Public Works of the city and at the California Regional Water Quality Control Board, San Francisco Bay Region (RWQCB).

Bioassays were made using three-spine stickleback as the test fish in accordance with requirements of the RWQCB for routine monitoring. Results of these 96-hour tests are summarized in Table 6-21 for each of the three sewerage service areas of the city and for the entire city. As in the case of the bioassays of dry weather wastewater and effluents, somewhat higher toxicity was found in the wastewater overflows from the industrialized Southeast service area than in the others. For the city as a whole, 100 percent survival was attained in the undiluted wastewater of more than one-half of the samples.

In terms of toxicity concentration, as defined in Table 6-20, the log mean concentration was 0.75 toxicity unit for the entire city, and 90 percent had concentrations equal to or less than 1.3 toxicity units. The log mean value is presented because toxicity is a logarithmic function of percent survival. The calculated equivalent mean survival in the undiluted wastewater is 80 percent.

Table 6-21. Results of 96-hour Stickleback Bioassays of Wastewater Overflow Samples, December 1972 - July 15, 1975

Drainage district	Richmond-Sunset	North Point	South-east	Entire City
Number of samples[a]	61	72	57	190
Toxicity units[b]				
Median	<0.59[c]	<0.59[c]	0.76	<0.59[c]
Mean[d]	0.66	0.76	0.85	0.75
90 percentile	1.2	1.3	1.8	1.3
Maximum	3.12	2.86	>12.5	>12.5

[a] Samples collected from overflows to San Francisco Bay or to Pacific Ocean during rainstorms. Three-spine stickleback were used as the test organisms.

[b] Toxicity concentration, expressed as toxicity units, is defined as follows:

$$T_C = \frac{100}{96\text{-hr } TL_m, \%}$$

or for more than 50% survival in undiluted wastewater,

$$T_C = \frac{\log (100-S)}{1.7} \quad \text{where}$$

S = Percent survival in undiluted wastewater.

[c] T_C values of less than 0.59 occur with 100 percent survival of 10 test fish in an undiluted sample.

[d] Calculated as the log mean assuming value of 0.50 where <0.59 is reported.

DISCUSSION OF TOXICITY RESULTS

This section presents a discussion of the toxicity studies on pilot plant effluents using selected marine fishes and invertebrates as test organisms. The experimental approach is discussed first, then the findings of the study are discussed and compared with the findings of the previous study.

Experimental Design

The experimental design emphasized the use of short-term bioassay tests of 96 hour duration to measure acute toxicity. These were augmented by chronic

bioassays which tested longer term effects from wastewater exposure. Only one life stage was tested in most experiments although the Dungeness crab egg hatching and chronic experiments tested the effects of wastewater effluents on the hatching and molting processes. In spite of the variety of organisms and conditions tested during the course of this study, there are definite qualifications to be considered when attempting to extrapolate the results of laboratory experiments to the natural environment.

First and foremost, it must be remembered that laboratory experiments are carried out under a set of specified conditions, and the results are, therefore, operationally defined. The experimental design used in this study involved varying one or two parameters while attempting to hold the others constant. Admittedly, this is a simplistic approach, but it is the only practical one. Static bioassays were employed instead of continuous-flow bioassays because more conditions could be tested. Pilot plant effluents collected on as many different days as possible were tested to maximize replication. The large volumes of water required for the fish and shrimp bioassays limited the replication that could be achieved within an experiment, but all test conditions were run in triplicate in the crab experiments.

An important uncontrollable variable was the day-to-day changes in the quality of the pilot plant effluents. The influent feeds to both the North Point and Southeast WPCP have been shown to vary considerably (CH2M Hill, Inc., 1974). The Southeast WPCP receives industrial effluent which at times contains large concentrations of toxic materials. Surface runoff in the rainy season can also alter effluent quality. Even during normal operations, the pilot plant effluent from the ferric chloride flocculation and sedimentation process was subject to change from salt water intrusions which caused short-circuiting in the sedimentation tank. All of these factors contributed to the variability of effluent quality.

The test organisms themselves must also be considered as uncontrollable variables since considerable variability exists among individuals of the same species. All too often, this fact is overlooked, especially when few experiments are performed. As an example, the results of the egg hatching experiment L-H were markedly different from the other three experiments. Because of the low numbers of zoeae obtained in the controls, the results were discarded. However, taken by itself, experiment L-H could have led to a different conclusion. In addition to natural variability, collection and maintenance procedures can also have an effect. This was demonstrated in the shiner surfperch tests when the incidences of bacterial fin rot disease were encountered. Unfortunately, in an attempt to avoid the problems of biological variability, other variables are introduced. When only healthy organisms are used in bioassay tests, much of the natural variability is removed. This bias must be considered when laboratory results are extrapolated to the environment.

Another variable to be considered here is the marine environment itself. Most of the conditions tested in the study were far more severe than would be encountered in the natural environment. Considering the mixing processes involved, the probability of a fish or shrimp being exposed to undiluted effluent is remote, and even if it did occur, the exposure to conditions of reduced salinity would probably cause more stress than effluent constituents. In the bioassay tests, the organisms were exposed to the same effluent concentrations for a minimum of 24 hours whereas in the natural estuarine or marine environment it is unlikely that an organism would be exposed to the same solution for any significant period of time. The results of the toxicity tests in this study, both acute and chronic, are probably conservative,

since these results reflect far more severe conditions than are likely to be encountered in nature. On a short-term basis, it is probably safe to extrapolate the bioassay results to natural populations, but laboratory bioassay tests provide little information on the effects of exposure to minute amounts of wastewater through several life stages or generations.

Finally, it should be pointed out that laboratory experiments only measure such direct effects as death or reduced activity. Subtle indirect effects may change the ability of a species to survive in a given area. Indirect effects may also manifest themselves by altering some component of the food chain on which the test organism depends. None of these effects can be measured in laboratory experiments since the whole ecosystem must be considered.

Comparison of Results with Previous Studies

The toxicity of primary effluents from the city's primary treatment plants was studied using a variety of marine fishes and invertebrates (Brown and Caldwell, 1971, 1973). In the first study, effluent samples from North Point, Richmond-Sunset, and Southeast WPCP were composited in proportion to flow and tested in both acute and chronic toxicity bioassays. The second study tested mixtures of wastewater from only the Richmond-Sunset and Southeast WPCP, since the engineering studies at that time indicated that North Point effluent would be discharged separately. The present study emphasized pilot plant effluents using influent feeds from the Southeast WPCP and from a three-to-one North Point-Southeast WPCP mixture. One of the processes tested was air activated sludge; the other was ferric chloride flocculation and sedimentation with and without filtration and activated carbon sorption. Primary effluents were not tested in conjunction with the pilot plant effluents except in four acute toxicity experiments with crab zoeae. Monthly acute toxicity bioassays with sticklebacks as test organisms were run on primary effluent samples from both the North Point and Southeast WPCP.

Fish and Shrimp Studies. Results of the 96 hour acute toxicity bioassays in the previous study (Brown and Caldwell, 1971) generally showed that the primary effluents tested became acutely toxic at dilutions less than 3:1 (33 percent concentration). In the present study, comparable bioassays failed to detect 96 hour acute toxicity even in undiluted effluent (salinity adjusted to 28 parts per thousand). The survival percentage remained above 50 percent in all but three tests and two of these were in the preliminary tests in which most of the shiner surfperch were infected with bacterial fin rot disease irrespective of the wastewater concentration. It is difficult to estimate how much of this improvement in the toxicity results is directly attributable to the upgraded treatment, since tests on primary effluents were not run concurrently under identical test conditions. The results of the present study do indicate, however, that any of the test species could withstand short-term exposure to high concentrations of either pilot plant effluent in the natural environment without adverse effects.

Extended term bioassays were run to check for chronic toxicity effects. In the present study only undiluted effluents with salinity adjustments were tested. The English sole tests resulted in respective survival percentages of 95 and 100 in the undiluted activated sludge and ferric chloride flocculation effluents using the Southeast WPCP influent feed. However, survival dropped to 70 and 80 percent, respectively, after 23 days exposure to the North Point-Southeast WPCP effluent mixture. Shiner surfperch had relatively low survival in the Southeast WPCP effluents with respective averages of 25 and 45 percent after 13 days, possibly because of bacterial fin rot infections, but survival was 95 and 100 percent,

respectively, in the North Point-Southeast WPCP effluent mixture. The most important factor in interpreting these results is that the tests were run with undiluted effluents. Therefore, any toxicity recorded in these experiments occurred at concentrations much greater than those to which organisms would be exposed in the natural environment. No comparable long-term bioassay tests were performed in the previous study so a comparison between the long-term effects of primary effluents and higher treated effluents cannot be made.

Crab Studies. The effect of exposure to primary effluents was tested in two previous studies on Dungeness crab eggs and zoeae (Brown and Caldwell, 1971, 1973). These studies were plagued by the incidence of terminal prezoeae, both in the controls and wastewater dilutions. In the egg hatching experiment reported in the first study, 85 and 93 percent of the eggs ultimately resulted in first stage zoeae in the control and one percent effluent concentration, respectively. In the five and 10 percent concentrations, the respective percentages of first stage zoeae obtained were 36 and 42, but in addition 30 and 44 percent of the eggs, respectively, remained as prezoeae that did not molt to first stage zoeae. The occurrence of these high percentages of prezoeae at the end of the 96 hours indicated that there was stress. Therefore, another egg hatching was performed during the 1971-72 crab hatching season. This experiment, reported in 1973, was performed in a continuous-flow apparatus rather than in a batch assay. The original number of eggs was not recorded, but an analysis of variance of the ratios of zoeae to prezoeae failed to detect any significant differences among the controls and wastewater concentrations which ranged from 0.5 to 2 percent. However, this experiment was inconclusive because most of the prezoeae in each of the three control replicates failed to molt into first stage zoeae. In the present study, averages of 88.1 and 91.2 percent of the eggs resulted in first stage zoeae in four experiments with Steinhart and synthetic seawater controls, respectively. These high results may have been, in part, a result of using local crabs as the egg source. Previously, the crabs were transported from Oregon and Alaska. This contributed to the handling stresses which may have been responsible for the failure of prezoeae to molt to first stage zoeae. The results in the present study showed no effect of air activated sludge effluents on the percentage of zoeae obtained from eggs until a 50 percent effluent concentration was tested. There were, however, significantly fewer first stage zoeae obtained in the ferric chloride effluents. In two experiments, the effect was noted in influent concentrations as low as five percent. The incidence of a prolonged prezoeal stage was not a major problem in these experiments.

First stage zoeae were tested in 96-hour acute toxicity bioassay experiments in both previous studies as well as in the present study. The 1971 report indicates that survival was high in the controls, as well as in primary effluent concentrations up to five percent. The experiments reported in 1973 suffered from the fact that survival in the controls was low in some of the experiments; however, the overall average survival in the controls of the five experiments with one-day-old first stage zoeae was about 81 percent after 96 hours. A statistical analysis of these results failed to detect any significant differences among the controls and wastewater dilutions ranging from 0.5 to 5 percent. The results of the present study tend to support the results of these previous studies. Although primary effluent was tested in only one experiment, the results indicated that the effluent from Southeast WPCP was not toxic to first stage zoeae up to a concentration of 10 percent when the salinity was adjusted to 25 ppt. When the salinity was lowered to 12 ppt the 10 percent concentration was toxic. The activated sludge and ferric chloride flocculation effluents from the pilot plant did not show 96 hour acute toxicity at 10 to 20 percent concentrations when salinity was maintained at 25 ppt in nine experiments. Both effluents caused adverse effects at 50 percent concentrations although statistically significant mortality was exhibited only in the

ferric chloride flocculation effluent. When salinity was maintained at 12 ppt, mortality occurred in the 20 percent ferric chloride flocculation effluent concentrations.

Several chronic toxicity experiments on crab zoeae were performed in the previous study (Brown and Caldwell, 1971). Composited samples of primary effluent from the city's three treatment plants were tested at concentrations up to five percent. Mortality in the effluent dilutions was similar to that obtained in the controls. Static tests were run with one-, five-, and twenty-day-old first stage zoeae and a continuous-flow test was run with one-day-old first stage zoeae. In each case, the highest mortality rate appeared to be associated with the molting process. The results of these experiments were judged inconclusive, but there is also a definite possibility that the primary effluents were not toxic at the levels tested. Only the static bioassays using one-day-old zoeae tested the five percent effluent concentrations; the remaining tests used effluent concentrations no higher than two percent.

In the present chronic toxicity study, effluent concentrations ranging up to 10 percent were tested. Two experiments were run and effluents from the air activated sludge and ferric chloride flocculation and sedimentation processes were tested using one-day-old first stage zoeae. The first experiment was run for 25 days and the second for 15 days. The survival in air activated sludge effluents was similar to that obtained in the controls in both experiments. Survival in the five and ten percent concentrations of ferric chloride flocculation sedimentation effluent was markedly lower than in the controls. In contrast with previous experiments, there did not appear to be an increase in mortality rate associated with the molting process. In the 25 day experiment, first stage zoeae successfully molted into second stage zoeae without appreciable mortality. The second experiment was terminated before the molting process began.

In view of the present findings, it is likely that much of the mortality associated with the molting in previous experiments was caused by handling stresses, since zoeae are particularly vulnerable during the molting process. An important factor may have been temperature, since it has been demonstrated that increases in temperature can cause premature molting (Poole, 1966 and Reed, 1969). In previous studies, zoeae were subjected to rapid temperature changes during counting procedures. In the present study, care was taken to keep temperatures constant in the experimental flasks and never to remove zoeae from the temperature-controlled environmental room. Other stress factors may also have contributed to the problems in previous experiments, but temperature was probably the most important single factor.

A comparison of all the chronic toxicity results shows that no toxicity has been measured at the one percent concentrations of any of the effluents tested. Under laboratory conditions, the long-term (10 days or more) toxicity threshold for primary effluent is probably near the five percent level. The comparable threshold toxicity concentration for the air activated sludge effluents is in excess of 10 percent whereas the five percent concentration of the ferric chloride flocculation effluent was definitely toxic under the conditions tested. Direct comparisons between previous results and the present data should be made with care because of the differences in the quality of the sewage. The composited primary effluents reflected influent from the entire city whereas the pilot plant effluents reflected only the industrial Southeast WPCP service area. A highly toxic effluent on one day can kill all the test

organisms. This probably happened in the 50 day experiment in the present study, since most of the mortality in the five and ten percent concentrations of ferric chloride flocculation and sedimentation effluent occurred on one day. This type of massive mortality masks the more subtle long-term effects. Thus, chronic toxicity bioassays may just be a summation of a series of acute toxicity bioassays. On the other hand, it is significant that high percentages of zoeae were able to survive and molt in wastewater concentrations even as high as one percent, since it is unlikely that a planktonic organism would be exposed to this level for such an extended period of time in the natural environment.

CHAPTER 7

DESIGN CRITERIA AND ALTERNATIVE PLANS FOR MARINE WASTE DISPOSAL

This chapter assembles the relevant biological and oceanographic information needed for outfall and diffuser design, discusses the outfall and diffuser design recommendations, and evaluates the predicted performance of different effluent disposal alternatives. Volume I of the 1971 report presented design criteria for effluent disposal in the ocean and in the bay at North Point. At that time, it was assumed that the discharge through the existing submarine outfall from the Southeast Water Pollution Control Plant would either be in operation or be abandoned when an ocean outfall was constructed. The report also recommended outfall sites for ocean and bay discharge alternatives and specific diffuser designs.

Information gained in the biological and oceanographic studies discussed in previous chapters of this report is used in this chapter to review and update the design criteria and preliminary outfall designs for ocean disposal alternatives. The data from previous studies which are pertinent to the development of criteria and preliminary designs for increased discharges at the Southeast site include physical oceanographic data for the bay contained in Volumes I and II of the 1971 report, data from other bay studies, and dispersion information from the mathematical water quality control model used to prepare the Water Quality Control Plan, San Francisco Bay Basin.

Biological criteria developed and discussed herein define minimum dilutions of effluent which should be permitted to continuously contact shallow water, bottom sediment, and water column habitats in the marine environment. The results of the most recent toxicity studies are used to develop these criteria.

WASTEWATER MASTER PLAN PROJECT

The San Francisco Wastewater Master Plan envisions a series of transfer pipes to convey all the dry and wet weather flow to a treatment plant site south of the San Francisco Zoo. Secondary treatment by the activated sludge process would be provided for a dry weather peak flow rate of 215 mgd for the year 2020. Chemically-augmented primary treatment is proposed for flow during wet weather beyond the capacity of the secondary treatment plant up to a total rate of flow of 1,000 mgd for all treated wastewater. Effluents would be discharged to the ocean through submarine outfalls and diffusers. A dry weather outfall would discharge secondary effluent at all times. A second, or wet weather outfall would discharge the treated excess wet weather flow. Implementation of the wastewater master plan would result in a reduction in the number of direct overflows of untreated combined wastewater during wet weather to an average of 8 occurrences per year.

In the first phase of implementation, the plan proposes that the wet weather outfall be used for discharge of both treated dry weather flow and excess wet weather wastewater from the Richmond-Sunset District.

Disposal Alternatives

Alternatives exist with regard to collection, transport, treatment and disposal of dry weather and wet weather flows generated in San Francisco, and two of these alternatives are discussed here for comparison with that recommended in the wastewater master plan. The alternatives include: (1) all dry and wet weather flow to the ocean (master plan recommended); (2) dry and wet weather flow to be treated at a new plant at the Southeast WPCP (Water Pollution Central Plant) site and discharged to the bay near the Southeast site, and (3) dry weather flows from the North Point and Southeast service areas to be treated at the Southeast WPCP site and discharged to the bay, with dry weather flows from the Richmond-Sunset service area and all wet weather flow from the entire city discharged to the ocean.

Volume of Wastewater

The peak rates of dry weather flow, projected for the year 2020, are listed for each of the alternative plans in Table 7-1. Also given are the expected average daily rates of flow. These values do not include wastewater which may be received under a proposed contract for service to the North San Mateo County Sanitation District. The amount of that flow, if accepted, would not greatly effect the sizing and cost of the proposed outfalls and would not change their performance.

The volume of wet weather flow in excess of the peak rate of dry weather flow will range from zero to 785 mgd. In August 1975 the Department of Public Works of the city completed a wet weather hydraulic analysis based upon 66 years of rainfall records. Results are based upon completion of the master plan and for year 2020 dry weather flow. The peak rate of wet weather flow to be treated and discharged via an outfall will occur about 30 times per year, on the average, and will last about 3.5 hours. The average interval between such events is 100 hours. A wet weather flow rate equal to or greater than 500 mgd in excess of peak dry weather rate would occur on an average about 40 times for a total of 150 hours per year.

With respect to the entire range of wet weather flow in excess of peak rate for dry weather, some flow will occur about 300 hours per year, or less than 4 percent of the time. Monthly, hours with some wet weather flow range from zero in July to 80 in January. Of the 300 hours per year, 275 hours or 92 percent occur between the beginning of November and the end of May, when local runoff and Delta outflow can promote surface outflow from the bay typical of the winter oceanographic season. The average for October is 16 hours. during that month the peak rate would, on the average, occur twice with a total duration of 5 hours.

Treatment to be Provided

The San Francisco Wastewater Master Plan provides for primary plus activated sludge secondary treatment for all flow up to an expected future dry weather peak rate of 215 mgd. For wet weather flow in excess of 215 mgd and up to a combined total of 1,000 mgd, treatment would be by chemically-augmented primary treatment such as lime plus ferric chloride flocculation and sedimentation. In either case, the design would necessarily provide for essentially complete removal of floatable matter and for disinfection as required to meet receiving water quality criteria.

Table 7-1. Rate of Flow for Design of Alternative Dry Weather and Wet Weather Outfalls

Alternative[a]	Design flow (peak rate), mgd[b]		
	1	2	3
Dry weather outfall			
to ocean	215[c]	0	65[d]
to bay	0	215[c]	180[d]
Wet weather outfall			
to ocean	785	0	755
to bay	0	785	0

[a]Alternative 1. All dry weather flow and wet weather flow to ocean

Alternative 2. All dry weather flow and wet weather flow to bay

Alternative 3. North Point and Southeast dry weather flow to bay, Richmond Sunset dry weather flow to ocean, wet weather flow to ocean

[b]Excluding minor flows which may be contributed from San Mateo County by proposed agreement with City. Effect of such flows on outfall design would be minor.

[c]Average dry weather flow would be 125 mgd.

[d]Average dry weather flow would be 105 mgd to the bay and 28 mgd to the ocean.

The proposed treatment is in our opinion entirely adequate to meet both present and possible future requirements for discharge to the ocean through suitably sited and designed submarine outfalls. We expect it to be adequate to meet present requirements for submarine disposal to the bay near the Southeast plant site. Possible future requirements for disposal to the bay, however, are more difficult to foresee. Two items of concern are the gathering of shellfish for food and the removal of nitrogen from discharges to the South Bay.

The Water Quality Control Plan, San Francisco Bay Basin (State Water Resources Control Board, 1975) lists the taking of shellfish as an impaired beneficial use in both the central and south sectors of San Francisco Bay. It sets as a goal the enhancement

of the quality of bay waters to permit unrestricted harvesting of shellfish in areas capable of supporting such use. If promulgated as policy, this could require the upgrading of treatment facilities to assure a very high degree of disinfection at all times. Effluent filtration, for example, may be needed to meet that goal.

With respect to nitrogen removal, investigations leading to the basin water quality plan showed that total nitrogen concentrations in the extreme south end of the bay are now high and that treatment for nitrogen removal may be needed in the future to prevent excessive entrophication. A question arose as to what extent nitrogen discharged by San Francisco to the bay would affect the remaining nitrogen concentration in the South Bay if other dischargers to the south were required to remove nitrogen.

The development of an improved mathematical water quality model was included in the study for the basin plan and was used to predict receiving water characteristics under various conditions of freshwater inflow and of waste load inputs to the bay. One of the subtasks of the present investigation was therefore to use the model to show the effect of a major discharge from San Francisco to the bay near the Southeast WPCP. While the effect on nitrogen concentration was of primary interest, data were also obtained with respect to toxicity and to ultimate oxygen demand.

The assumptions and results of this subtask are presented in Appendix E. The results are also presented in Table 7-2 and are summarized as follows:

1. The discharge to the bay of the secondary effluent derived from the North Point-Southeast WPCP service areas would contribute 4 to 5 percent of the total nitrogen present in the nitrogen-sensitive southern reach of the bay after local dischargers provide for its removal. Although this nitrogen, along with a like amount from the East Bay, may be considered a significant fraction, we do not believe it is sufficient to warrant a future requirement for nitrogen removal for a San Francisco discharge to the bay.

2. The model indicates that the portion of the effluent which would be dispersed southward into the main body of the South Bay would achieve a steady state dilution of about 250 to 1 during a summer of minimum inflow to the bay. The model, however, does not take into account density stratification which occurs to a degree even in the summer in the northern portion of the South Bay and enhances seaward advection from there.

DESIGN CRITERIA

Site selection and design of submarine outfalls for disposal of effluent marine waters must take into account (1) applicable requirements and objectives of federal and state agencies including those concerned with public health aspects and aesthetic considerations, (2) biological criteria with respect to the local habitat of marine organisms and to the measured toxicity of effluent to the organisms, and (3) oceanographic criteria which control the vertical location and subsequent dispersion of an effluent field.

Table 7-2. Results of Malthematical Water Quality Model Analysis

Parameter	Model node and location				
	3	17	20	32	44
	S. of Yerba Buena	Hunters Point	Brisbane	Mid South Bay	N. of Dumbarton Bridge
Total nitrogen, mg/l					
1. NP-SE to ocean[a]	0.56	0.68	0.73	1.11	2.76
2. NP-SE to bay, secondary tr.[a]	0.60	0.75	0.79	1.17	2.82
3. NP-SE to ocean[b]	0.50	0.54	0.57	0.64	0.86
4. NP-SE to bay, nitrification[b]	0.52	0.59	0.62	0.69	0.90
Toxicity, in toxicity units					
1. NP-SE to ocean[a]	0.015	0.017	0.018	0.026	0.057
2. NP-SE to bay, secondary tr.[a]	0.015	0.019	0.020	0.027	0.058
3. NP-SE to ocean[b]	0.014	0.016	0.016	0.022	0.045
4. NP-SE to bay, nitrification[b]	0.014	0.017	0.018	0.024	0.047
Ultimate oxygen demand mg/l					
1. NP-SE to ocean[a]	0.23	0.24	0.19	0.17	1.00
2. NP-SE to bay, secondary tr.[a]	0.31	0.39	0.29	0.21	0.98
3. NP-SE to ocean[b]	0.15	0.12	0.11	0.10	0.71
4. NP-SE to bay, nitrification[b]	0.16	0.16	0.13	0.11	0.70

[a] South bay dischargers to provide nitrification, no discharge south of Dumbarton Bridge.

[b] South bay dischargers to provide for nitrogen removal; East Bay and San Francisco (if to bay) to provide for nitrification.

Objectives and Requirements of Regulatory Agencies

Other than to require secondary treatment for disposal of dry weather effluent to the ocean, as for other receiving waters, the EPA (U.S. Environmental Protection Agency) has not issued regulations specifically applicable to outfall siting and design. For wet weather flow from combined sewers a lesser degree of treatment is acceptable and is to be determined on a case by case basis.

Approval of an outfall project by the U.S. Corps of Engineers is necessary both with respect to navigation hazards and to disposal of excavated bottom material. Minimum allowable vertical clearance between a submerged structure and the water surface at extreme low water is 40 feet in areas of the ocean and the bay otherwise suitable for navigation by ocean vessels and in channels maintained for that purpose. Greater clearance is desirable for protection of a submarine outfall.

Regulations on disposal of dredge materials from trenching in the ocean or bay bottom require core sampling to the full depth of the trench and analysis of the strata in each core for physical and chemical characteristics. Available information indi-

cates that there should be no problem with toxicants or pollutants in the ocean bottom and probably none for a bay outfall. However, anticipated new regulations could be interpreted to require that silty sand from an ocean site be carried back into the bay for disposal near Alcatraz Island.

Objectives and general requirements of the State of California with respect to marine waste disposal are set forth in three documents. These are (1) Water Quality Control Plan for Ocean Waters of California, adopted by the SWRCB (State Water Resources Control Board) July 6, 1972, (2) Water Quality Control Policy for Enclosed Bays and Estuaries of California adopted by the SWRCB May 16, 1974 and (3) Water Quality Control Plan, San Francisco Bay Basin, 1975. Specific requirements which are typical of those expected to be applied to a dry weather outfall serving the entire city are contained in NPDES (National Pollution Discharge Elimination System) Permit No. CA0037681 for the Richmond-Sunset Water Pollution Control Plant issued in December, 1974, by the Regional Water Pollution Control Board.

Objectives and principles for management contained in the Water Quality Plan for Ocean Waters call for the following:

1. A zone within 1,000 feet of the shore or to the 30 feet depth contour, whichever is greater, shall meet state bacteriological objectives for body-contact sports. All areas where shellfish may be harvested for human consumption shall meet bacteriological objectives for such use.

2. Floating particulates of waste origin, grease, or oil shall not be visible. The concentration of these materials on the surface shall meet stated limits.

3. The discharge shall not cause aesthetically undesirable discoloration of the ocean surface. The transmittance of natural light shall not be significantly reduced outside the initial dilution zone.

4. Marine communities, including vertebrate, invertebrate, and plant species shall not be degraded. The final toxicity concentration shall not exceed 0.05 toxicity units.

5. Ocean outfalls and diffusion systems must be designed to achieve rapid initial dilution and effective dispersion to minimize concentrations of substances not removed by treatment. Initial rapid dilution should provide dilution exceeding 100 to 1 at least 50 percent of the time and exceeding 80 to 1 at least 90 percent of the time. Effluent quality requirements include a toxicity concentration not exceeding 1.5 toxicity units 50 percent of the time nor 2.0 toxicity units 10 percent of the time.

The Water Quality Control Policy for the Enclosed Bays and Estuaries of California includes as an objective the prohibition of discharges of untreated waste to bays, including wastes from combined sewers. As a matter of policy, bay or estuarine diffuser systems shall be designed to achieve the most rapid initial dilution practicable to minimize concentrations of substances not removed by source control or treatment. Discharges shall not be made into or adjacent to areas where the protection of beneficial uses requires spatial separation from waste fields.

The Water Quality Control Plan, San Francisco Bay Basin, includes the objectives of the ocean plan and the bay and estuaries policy. In addition, it provides a basis for evaluating bioassay results and other wastewater characteristics pertaining to toxicity criteria. It recommends a maximum steady-state toxicity concentration of 0.03 for the ocean and 0.04 for the bay. The toxic form of ammonia, (its un-ionized state) shall not exceed 0.025 milligrams per liter in the receiving water.

The basin plan provides that for deep water discharges to the bay, the survival of test fishes in 96-hour bioassays of the effluent shall be a 90 percentile value of not less than 50 percent survival. Exception may be made when (1) discharge is through a deep water outfall which achieves rapid and high initial dilution and the waste is rapidly rendered non-acutely toxic upon discharge, and (2) the toxicants are non-conservative constituents which are rapidly decayed in the receiving water; or the toxicants in the waste are conservative constituents for which water quality objectives have been established. The Regional Board will, in such cases, establish effluent mass emission rates for such constituents.

For shallow water discharges to the bay the survival of test fishes in 96-hour bioassays shall be a median of 90 percent survival and a 90 percentile value of not less than 70 percent survival.

The NPDES permit applies to the dry weather flow. It includes effluent characteristics combining both the BOD, suspended solids, and bacteriological requirements for secondary treatment by the EPA, and the effluent limitations of the State Water Quality Control Plan for Ocean Waters. Receiving water limitations after initial dilution likewise are as called for by the ocean plan.

A requirement of the permit applicable to an ocean outfall prohibits discharge within 1,000 feet offshore from extreme low waterline and from locations where the waste will not receive a minimum dilution of 100 to 1 as it reaches the surface.

Biological Criteria

The objective of research on lethal and sublethal effects of wastewater effluents on aquatic organisms is to provide a basis for prediction of the effluent concentrations that can be assured to be not deleterious to the survival, growth, reproduction and general well-being of biota which could be continuously exposed to effluent concentrations. A firm definition of such "safe" concentrations has often been treated in the literature as an almost hypothetical future goal. However, there have been many direct attempts to make quantitative estimates of safe concentrations and some of those efforts are relevant to establishment of biological design criteria for San Francisco.

So-called safe or no-effect concentrations have historically been estimated using application or safety factors. The application factor, as used in a fisheries and pollution evaluation context, provides a means of predicting a safe level based upon data collected at concentrations which result in a statistically significant level of effect. The concentration which produces an effect is multiplied by an application factor to obtain a reduced concentration which presumably has no chronic or sublethal effect. Conceptually, the application factor should provide a measure of safety not only for the more sensitive individuals of a given test species but also for organisms more sensitive than those tested. Likewise, application factors should provide protection against chronic or undesirable sublethal responses not readily detectable in the laboratory. The value of the application factor is assigned, based

upon the judgement of scientists, using available evidence on the relation between safe levels and lethal levels. In addition to the direct evidence observed in bioassays, consideration is also given to the difference between laboratory and natural conditions, to time of exposure, and to the nature of known toxicants.

The exposure time of organisms to wastewater constitutents in the environment will usually differ from the exposure time experienced in laboratory bioassays. Laboratory tests continuously expose test organisms to a generally constant concentration of wastewater constituents over a predetermined period, usually four days. In an estuary or the ocean, unlike a river or lake, an effluent field continuously changes position with the tides. Hence, free swimming pelagic organisms would stay within an area of constant effluent concentration only if they are attracted to it. Planktonic forms swept past the outfall in the current would not be exposed for four days to a given effluent concentration, as represented in a laboratory bioassay, because of the continuous dispersion and dilution of the effluent field.

As discussed in Chapter 6, the occurrence of stresses to test organisms preceding their exposure to wastewater in laboratory bioassays will cause the physiological condition of test organisms to be different than the condition of organisms in the natural environment. Stresses are associated with capture of test organisms in the environment and maintenance of those organisms in the laboratory. Removal of unhealthy organisms before testing can result in a program that exposes only the most healthy of those individuals which were collected, since the less healthy animals are culled out. Conversely, for species not readily adaptable to laboratory conditions, the stresses inherent in handling and testing of the bioassay organisms can enhance the toxic effect of the effluent exposure.

Third, water pollutants may be classed as persistent (conservative) or as nonpersistent (nonconservative) under natural environmental conditions. Persistent pollutants are those which do not lose their toxic effect with time or do so very slowly. Nonpersistent toxicants are those which lose their deleterious effect quite rapidly through natural degradation or a change to an inert form. Additive effects have been found to occur for some materials when concentrations are near their lethal values. However, in trace amounts many of the same materials have nutritional value.

Application factors, when selected, are applied to the results of bioassays expressed as a single numerical value. The 96-hour median tolerance limit (TL_{50}) is the usual measure and means the concentration, computed from the test results, in which 50 percent of the test organisms survive after exposure for 96-hours. A second measure is the toxicity concentration which is expressed in toxicity units. It is defined as equal to 100 divided by the 96-hour TL_{50} expressed in percent.

Thus: $$T_c = \frac{100}{96\text{-hr } TL_{50}},$$

Where: T_c = Toxicity concentration.

For an effluent in which 50 percent of the test organisms died in undiluted effluent (100 percent concentration) the effluent would have a toxicity concentration of 1.0 toxic unit. The TL_{50} becomes indeterminate, however, when more than 50 percent survival occurs in undiluted effluent. A relationship between such higher survival

of golden shiner (a freshwater fish) and toxicity concentration has been developed (Esvelt, 1972) and has been applied to other species such as the threespine stickleback, by the SWRCB. This relationship is

$$T_c = \frac{\text{Log } (100-S)}{1.7}$$

where S is percent survival in the undiluted effluent. For 100 percent survival of ten test animals, T_c becomes indeterminate and is expressed as less than 0.59 toxicity units. The Water Quality Control Plan, San Francisco Bay Basin states that where survival of large numbers of test animals exceeds 95 percent, corresponding to a T_c value of less than 0.41, reliance should be placed on chemical analyses for determination of toxicants.

A three-step procedure for evaluating low-level toxicity is recommended in Chapter 4 of the Water Quality Control Plan, San Francisco Bay Basin. The procedure is equally applicable to consideration of application factors. In brief, the three steps are as follows:

1. Evaluation of Water Quality Control Features. Evidence that the discharger will initiate a source control program and provide treatment processes capable of removing expected toxicants.

2. Evaluation of Wastewater Characteristics. Demonstration of low level toxicity through bioassays or, for very low levels, through chemical analysis for toxicants and summation of their individual toxicity values.

3. Determination of Dominant Toxicant. Identification of dominant toxicants and determination of their nature, that is, whether persistent or non-persistent.

A range of application factors was recommended in 1968 by the U.S. National Technical Advisory Committee (NTAC) to the Federal Water Pollution Control Administration. Some of the application factors recommended came from research cited in that report; others presumably are based on the special knowledge of the committee members. Generally speaking, recommended application factors range from 0.1 to 0.05 for nonpersistent pollutants and from 0.1 to 0.01 for persistent pollutants. An application factor of 0.01 is recommended for most of the persistent pollutants such as chlorinated hydrocarbon pesticides.

The Water Quality Control Plan, San Francisco Bay Basin, recommends that the toxicity concentration in tidal waters, expressed as a steady-state or continuous level, not exceed 0.03 to 0.05 toxicity units depending upon the sensitivity of the receiving waters. As an interim measure, values in the range of 0.06 to 0.1 toxicity units may be adopted. These values include the toxicity which may be present from all sources. The main water mass of San Francisco Bay is considered of average sensitivity. A low sensitivity may be applicable to harbor and marine shipping terminal areas. Ocean waters are generally considered highly sensitive.

Dilution Ratios for Dry Weather Discharge. Table 7-3 presents a summary of the results of pertinent bioassay experiments reported in Chapter 6 in terms of 96-hour TL_{50} and toxicity units. The shrimp and crab toxicity values do not take into account the relatively high mortality which occurred in the control bioassays. Tests

of the activated sludge effluent are applicable to the dry weather flow. For the very short time of exposure involved in the initial dilution and early dispersal of the effluent, an application factor of 0.1 applied to the 96-hour TL_{50} determined by any of the test organisms is conservative and would require a dilution ratio of 10 to 1.

Table 7-3. Summary of 96-hour TL_{50} and Toxicity Concentration Values

Test organism	Dry weather flow, activated sludge effluent		Wet weather flow, ferric chloride primary treatment except as noted		Data reference table
	96-hr TL_{50} [a]	Tc [b]	96-hr TL_{50} [a]	Tc [b]	
Shiner surfperch	> 100	< 0.41-0.45	> 100	0.50	6-4, 7, 9
English sole	>100	< 0.41-0.45	> 100	< 0.41	6-4, 7, 9
Bay shrimp	>100	0.75	> 100	0.84	6-4, 7, 9
Dungeness crab:					
Egg hatch	> 100[c]	0.63[c]	> 100[c]	0.90[c]	6-15
Larvae	>100[c]	0.56[c]	38	2.6	6-16, 17
Stickleback	>100	< 0.41	> 100	< 0.69	6-6, 10
Stickleback in untreated overflow			> 100	0.75[d]	6-20

[a] Median tolerance limit after 96-hour exposure

[b] Toxicity concentrations, in toxicity units (Tu)

[c] 96-hr TL_{50} calculated from survival in lower concentrations up to 50 percent. Tc was derived from the calculated survival in 100 percent effluent

[d] Geometric mean. Median value 0.59, 90 percentile value 1.3 Tu

For steady state conditions a maximum T_c of 0.03 in the ocean is called for by the basin plan. For the indicated toxicity to Dungeness crab egg hatching and larvae survival, a long-term dilution ratio of 60 to 1 would result in a toxicity concentration of 0.01, or one-third of the maximum value. The Water Quality Control Plan for Ocean Waters calls for rapid initial dilution and effective dispersion and suggests an initial dilution of 100 to 1 at least 50 percent of the time. Coupled with subsequent dispersion this would more than meet the basin requirement.

For the steady-state or long-term maximum toxicity in the bay, the basin plan calls for a maximum concentration of 0.04 toxicity units generally, or perhaps 0.05 units in the vicinity of port terminals. However, many other wastewater effluents are discharged to the bay and hence a long-term dilution to or below 0.01 units is desirable and may be required. Based upon the indicated effluent toxicity value of 0.75 utilizing bay shrimp, a long-term dilution of 75 to 1 is called for. This simple approach does not take into account the flushing rate of the bay currents. Based upon the results of the water quality model analysis shown in Table 7-2, discharge of an average daily volume of 125 mgd having a T_c of 0.75 toxicity units would increase the toxicity of the receiving water southward from an outfall by 0.0035 units. No increase would occur northward.

Dilution Ratios for Wet Weather Discharge. In developing application factors for the wet weather discharges recognition must be given to a number of points of difference between dry and wet weather flow. The most obvious of these is the intermittent nature of the wet weather discharge. As noted earlier, wet weather flow in any amount occurs 300 hours per year or only four percent of the time. The design peak flow will occur only 30 times per year, on the average, and for about 100 hours per year. Periods of higher than normal rainfall, both in frequency and intensity, do occur. These periods, however, increase the flushing rate of the bay and the seaward advection of surface waters in the Gulf of the Farallones. For these reasons, wet weather flow discharged near the central portion of the bay or into the ocean, unless highly toxic, would not be expected to contribute measurably to the steady-state or long-term toxicity level of the receiving waters.

A second difference is that pilot plant studies and effluent bioassays have not been made specifically of wet weather effluents. For this reason all pertinent evidence with respect to probable effluent quality needs to be examined.

A third difference is that as the rate (and duration) of wet weather flow increases, the strength of the waste with respect to most constituents decreases.

Bioassays from the pilot plant effluents applicable to the wet weather flow comprise those made of ferric chloride-augmented primary effluent without filtration and activated carbon sorption. Eight bioassays with fish, and two with shrimp (Tables 6-9 and -10) were made between October 18 and 24 in effluent derived from mixed dry weather flow from the North Point and Southeast service areas. Results, summarized in Table 7-3, show toxicity concentration values ranging from less than 0.41 for English sole to 0.84 for bay shrimp. Survival of the sole and surfperch was higher than that of the presumed hardier stickleback. For the two shrimp tests, average survival of the controls was 85 percent versus 73.5 percent in the undiluted effluent. If corrected for the losses in the controls, the toxicity concentration would be 0.66.

Bioassay experiments with Dungeness crab eggs and larvae were entirely on ferric chloride-augmented primary effluent derived from the Southeast service area, primarily dry weather flow. Values for T_c in Table 7-3, amounting to 0.90 and 2.6 respectively, are not corrected for losses in the controls even though a high mortality occurs in nature. Regardless of the appropriate toxicity value, the results of these tests were among the few to be found statistically significant by the chi square analyses for variance relating survival and effluent concentration.

The results of bioassays of untreated wet weather flow deserve major consideration because of their large number (190), because the wastewater was combined sewage and storm drainage and because the samples were representative of flow from the entire city. Since the wastewater was collected early in the overflow period, its concentration of material flushed from the sewers was probably higher than average. Average 96-hour toxicity to stickleback was 0.75 toxicity untis, calculated as the geometric (or logarithmic) mean of the toxicity concentrations of the undividual tests. The geometric mean was used to be comparable to the other toxicity values computed from average survival. Median survival was 100 percent, corresponding to a toxicity concentration of less than 0.59.

Other factors to be considered, as called for in the Water Quality Control Plan, San Francisco Basin, are toxicity source control, toxic matter found present by chemical analysis, and nature of the dominant toxicants.

Review of Chapter 6, Toxicity Studies, shows quite clearly that wastewater and effluents derived entirely from the industrialized Southeast service area usually exhibit somewhat higher toxicity than those from mixed North Point-Southeast sources. The city has embarked on a comprehensive program of industrial waste control. This is to reduce the effect of the wastes on treatment plant operation and to control the discharge of toxic matter at its sources. The NPDES permits issued to the city require that the source control program be developed and ready for effective control by mid-1976.

Complete chemical analyses of influent wastewater and of effluents were regularly made during the pilot plant testing program for the August-October 1973 period but not later during the crab egg and larvae bioassay period. The analyses results are summarized in Appendix C along with effluent standards for comparison. Persistent and nonpersistent pollutants are identified by footnotes therein.

With respect to the untreated wastewater, many of the toxic pollutant concentrations are within limits for effluent standards. Exceptions occur among the heavy metals, particularly chromium, nickel, zinc, and, marginally, mercury. Wastewater solely from the Southeast generally shows higher median values and greater variability as shown by the high 90 percentile and maximum values for these metals. Source control is needed to reduce the influent concentrations.

The effect of the difference in quality of combined and of Southeast wastewater on the concentration of toxicants in the treated effluents is not marked. Median values for chromium differ little, for example, either with waste source or mode of treatment and the maximum value occurred in activated sludge effluent derived from combined wastewaters. Greater variability is indicated by high 90 percentile and maximum values for other heavy metals, notably nickel and zinc, in effluents derived from the Southeast source. This points to individual dumps and spills as being a principal mode of discharge of these toxicants to the sewers. Results of bioassays of effluents derived from Southeast sources were likewise typified by high variability.

The chemical analyses do reveal a principal difference between the ferric chloride-augmented primary effluent and the activated sludge effluent. Ammonia nitrogen and surfactant, both well-known nonpersistent toxicants, are present, as would be expected, in the chemically-augmented primary effluent in amounts which could affect survival in the lower dilutions of effluent. Compared with the known toxicity of chromium, these nonpersistent toxicants are dominant and could account for the difference in bioassay results between activated sludge effluent and the ferric chloride-primary treatment effluent.

Considering then the limited frequency duration of wet weather overflows, the industrial waste control program, the low level of persistent identifiable toxicants in chemically-augmented dry weather effluent and the identification of nonpersistent toxicants as dominant in that effluent, as application factor of 0.10 is appropriate. Applied to the TL_{50} of 38, a dilution ratio of 26 to 1 is required. For longer term needs, bearing in mind the intermittent nature of the discharge, a dilution ratio of 100 to 1 would fall within the 0.03 level called for a steady state maximum in the ocean.

Oceanographic Design Criteria

The general objectives of marine effluent disposal are to provide, as close to the point of discharge as possible, effluent dilutions which satisfy the water quality objectives of the regulatory agencies and to achieve dilutions needed to protect marine biota from adverse effects caused by exposure to residual toxic components of the effluent. When possible, the effluent should be entrained in currents which convey the effluent field away from the shoreline. For disposal in the Gulf of the Farallones, the effluent should be discharged in such a manner as to minimize the amount of effluent which would be carried toward the shore or into San Francisco Bay. The location and design of outfalls and diffusers to meet these objectives are strongly influenced by the oceanographic characteristics at the discharge site. The oceanographic information discussed here summarizes the pertinent factors which govern the design of outfalls for the alternative disposal sites in the Gulf of the Farallones and Central San Francisco Bay.

Design Criteria for Discharge to the Gulf of the Farallones. Oceanographic studies conducted in the Gulf of the Farallones are discussed in Volume I of the 1971 report and in Chapter III of this report. Alternative disposal sites for dry weather and wet weather effluents were presented in the 1971 report. The San Francisco Bar was found to be too shallow for a major outfall. Sites within the bar were carefully studied and rejected for two reasons. First, the density gradient of the water within the bar is such that a surface field could form at times during the summer and fall oceanographic seasons. Constraints with respect to navigation would place such a field only a mile offshore where it would be visible from the popular viewing points near Lands End and overlooking Seal Rocks. Second, high unit construction costs would be encountered because of unstable bottom conditions and high velocity tidal currents. For these reasons a tentative site was selected south of the bar pending further study during the critical fall season when seaward movement is the weakest and the density gradient in the water column is the least favorable.

The October 1973 studies showed that a dry weather diffuser should preferably be situated near Station 2, about 22,000 feet offshore in 80 feet of water. The currents in the fall have a net seaward movement at all depths. The distance offshore is sufficient to assure that the effluent field will stay beyond the more critical shore and intertidal zone.

A diffuser for the dry weather flow should be designed to achieve rapid initial dilution, as called for in the ocean plan, and to achieve a near-surface submerged field. The least favorable density gradient observed in the October 1973 survey will permit this to be achieved.

Based on mass water movements and other observations in 1970, a wet weather discharge south of the bar should be more than one mile offshore to prevent entrainment in the near-shore waters which have a net bayward movement. A minimum depth of 50 feet is required for navigation clearance over the diffuser. Because of the very few hours of use in October and because heavy rainfall itself initiates outflow from the bay typical of the winter condition, the winter season is used as the design condition.

The diffuser should be designed to attain a surface field during the winter oceanographic season. An effluent field entrained in the surface layer would be rapidly carried to the southwest in the ebb flow surface layer away from the Golden Gate. Initial dilution of the wet weather discharge must be low enough to assure penetration of the wet weather field into the upper, if not the surface layer. At high dilutions (therefore, higher effluent field density), the field could be diffused in the lower water layer which is known to have a high bayward displacement in the winter season due to increased tidal exchange.

Design Criteria for Discharge to San Francisco Bay. Oceanographic data in the vicinity of the Southeast WPCP were presented and discussed in Volume I. The possible location and configuration of effluent diffusers for alternative effluent disposal to the bay are severely constrained by dredging and maritime activity. However, the design objectives relative to the desirable position of the effluent field in the water column are similar to those expressed for the Gulf of the Farallones discharges. The wet and dry weather diffusers should attain as consistently as possible a surface or near-surface field to make use of the maximum dilution which is available in the water passing over the diffuser. Also, surface water located north of Hunters Point has a net seaward vector at most times of the year and ultimate transfer of the effluent to the ocean would occur more rapidly in the surface layer.

Design Features. The hydraulic factors in diffuser design allow a practical flow range of about 10 to 1. For greater flow ranges, either the head loss at the diffuser ports becomes excessive or port velocities become too low to assure an even flow distribution throughout the diffuser length. Two outfall diffusers are required to cover the range of flow from present minimum dry weather to wet weather peak rates.

Diffuser port diameters have generally been limited to 3-1/2 inches to permit manual inspection. However, recent experience has demonstrated the feasibility of using much smaller openings for secondary effluent. Port spacing is related to water depth when the design objective is to achieve maximum initial dilution. For small ports, though, the practical limit on spacing is about 4 to 6-foot port separation on alternate sides of the diffuser pipe. The port orientation in the vertical plane is usually horizontal or slightly downward for maximum initial dilution. Orientation of the port at a slightly upward angle can reduce exposure of benthic organisms to dilutions of the effluent in the vicinity of the diffuser.

The outfall conduits will be of precast reinforced concrete sections having gasketed joints capable of flexure and having bolted ties. Foundation, bedding and lateral support design against wave and current forces will depend upon results of soil and foundation studies. Pile support may be required for shore connnections and where soil liquefaction may occur during an earthquake. The dry weather outfall into the ocean will cross the San Andreas fault. Consideration will be given to special design features in this area which would accommodate creep and moderate transverse displacement without rupture.

Diffuser sections of the same diameter as the main stem of the outfalls and equipped with end gates will permit the use of cleaning tools. For the wet weather outfall, a diffuser port design which will prevent entry of seawater is necessary to avoid accumulations of silt and encrusting marine organisms during the dry weather season. Means for permitting a controlled occasional discharge of dry weather effluent through the wet weather outfall also may be necessary to control marine growths.

The dry and wet weather ocean outfalls may be constructed as two parallel pipes for part of their route, in which case a common pier through the surf zone could be erected for their construction. Alternatively, it may be feasible to construct parallel sections as a single structure having two conduits. Consideration should also be given to the possibility of a single conduit with a hydraulically controlled diversion gate to serve the wet weather diffuser. Pipeline or structural lengths described herein are only for the submarine portion of the outfall.

Outfall Construction Costs. Elements entering into the contract cost and the contingencies, engineering costs, and other allowances which make up the project construction cost are described in Volume I. Curves showing estimated contract costs in that volume have been reviewed against recent outfall contract costs and are found suitable for present use if adjusted for general cost increases. An ENR (Engineering News - Record) Construction Cost Index of 1900 was used in the 1971 report. Costs given herein are based on an ENR Index of 2500 corresponding to the 1975 level.

PRELIMINARY OUTFALL DESIGNS

The submarine outfall and diffuser design recommendations discussed in this section have been based upon the peak rates of flow for the three basic wastewater disposal alternatives defined in Table 7-1. Briefly restated, the disposal alternatives are; (1) all dry weather and wet weather flows to the ocean, (2) all dry weather and all wet weather flows to the bay, and (3) Richmond-Sunset dry weather and all wet weather flows to the ocean, Southeast and North Point dry weather flows to the bay.

Submarine outfalls convey the effluent to the discharge location where the effluent is diffused into the receiving water by means of multiple port outlets. Diffusers are designed basically in accordance with the principles described in Volume I of the 1971 report to achieve the degree of dilution appropriate for the site and the character of the wastewater, and to be consistent with the biological criteria developed to protect biota in the receiving water. However, more recent concepts relating current velocities and initial dilution have modified the concepts expressed in Volume I.

When effluent is forcefully discharged into quiet seawater, two forces act to provide immediate dilution. The first is the energy released by the dissipation of velocity of the jet. The second is the buoyant force which is proportional to the difference in density between the effluent and the surrounding salt water. The buoyant force bends a horizontal discharge towards the surface and accelerates its ascent. Because of the relative motion betwen the discharged sewage jet and the seawater, turbulence is generated and entrainment and mixing with ambient ocean

water takes place. Due to entrainment, the rising effluent-seawater mixture may achieve a density greater than that of the surface waters and thereby stratify at some depth beneath the surface where a condition of neutral buoyancy is established. The rising sewage plume usually surpasses this depth due to the vertical momentum of the plume, and then falls back to the depth of neutral buoyancy. A density gradient must exist in the water column to attain a submerged field; otherwise the effluent field will reach the surface.

In Volume 1, the prediction of initial dilution and the height of rise achieved by a continuously discharged buoyant effluent is based on the formulations of Brooks (1960) and Ditmars (1969) for the case of slack (no current) receiving waters. Since the presence of a current aids the dilution process, this is a conservative approach to the problem. The formulations take into account port diameter and angle from the horizontal, port distance along the diffuser, port discharge velocity, and the density structure of the water column.

Recent research on line sources in a nonstratified current by P. Roberts (1975) confirms that the dilution achieved in the presence of a current is substantially greater than predicted by the formulations for the slack water case. Roberts' experimental work on surface fields indicates that the initial dilution and field width of a buoyant effluent is dependent upon the length of a diffuser and a dimensionless densimetric Froude number (F), where:

$$F = u_a^3/b$$

where: u_a = current velocity,
b = buoyancy flux per unit length.

$$= \frac{(p_r - p_o)\ gq}{p_r}$$

where: p_r = density of receiving water,
p_o = density of effluent,
g = acceleration due to gravity,
q = volume flux per unit length (Q/L),
Q = total volume flux of effluent,
L = diffuser length.

Roberts found an experimentally determined relationship between the Froude number and the dimensionless variable,

$$\frac{S_m q}{u_{aH}}$$

where: S_m = minimum initial dilution on the surface, and
H = water depth.

Roberts' work has also shown that the width of the effluent field after it is first formed is governed by buoyant spreading of the effluent within the receiving water, and that the spreading rate is greater at smaller Froude numbers. Furthermore, the work indicated that for a current perpendicular to the diffuser and Froude numbers greater than about 0.2 (i.e., high currents and/or low discharges), the waste field is initially mixed over the whole depth interval H, thus making contact with the bottom. However, under these conditions, the field rises to form the typical surface field downstream of the location of discharge.

At this time, Roberts' formulations are limited to experimental conditions which include discharge from a continuous vertical slot at low initial velocity into a water body having a uniform current and density from bottom to top and a resulting surface effluent field. Further, the result became indeterminate for low velocity currents and does not include the effect of jet velocity which then may predominate. Thus for outfall design the results of the solutions presented by Brooks (1960) and Ditmars (1969) and the results of Roberts (1975) have all been used in order to estimate the initial dilution which will be achieved in the Gulf of Farallones and San Francisco Bay in the vicinity of the proposed dry weather and wet weather. Discharges Volume I concepts were used to estimate the height of rise and thickness of the buoyant plume. The experimental results of Roberts were then used to estimate the initial dilution and field width. The results of these calculations for measured or estimated fall, summer and winter conditions are discussed in subsequent sections of this chapter.

The actual outfall and diffuser design will require geological investigations to assure a firm foundation for the outfall throughout its length. The outfall and diffuser designs noted here must be considered preliminary, as the outfall route and actual diffuser location may need to be adjusted as geologic data become available.

Subsequent dilution of an effluent is due principally to diffusion phenomena. While initial dilution induced by the effluent diffuser is a principal factor in diffuser location and design, subsequent dilution is important in reaching within as short a distance as practicable the longer term dilution required as a safe level for receiving water biota. Estimates of subsequent dilution for the preliminary outfall and diffuser design in the ocean disposal alternative (Alternate 1) are given in this chapter for the three oceanographic seasons following the actual presentation of the preliminary outfall and diffuser designs.

Preliminary Outfall Designs for Effluent Disposal - Alternative 1

Alternative 1, the effluent disposal recommendation of the San Francisco Wastewater Master Plan, assumes discharge of both dry weather and wet weather effluent to the ocean. The dry weather outfall recommended and described under the Option 4, Site D on pages 195-197, Volume I, R971, report generally meets the current requirements. However, the size of the outfall and diffuser length have been changed slightly, reflecting a reevaluation of the maximum dry weather flows. The proposed dry weather outfall design required 22,000 feet of 90-inch pipeline. A 1,240-foot diffuser section constructed at a depth of 80 feet will have 200 3.5-inch ports spaced alternately at 6-foot intervals on opposite sides of the pipe, oriented at 30 degrees above the horizontal. The diffuser location, shown in Fig. 7-1, is approximately three and one-half nautical miles offshore, about two miles south of Fleishhacker Pool. The diffuser orientation would be on an east-west axis with the shoreward terminus of the diffuser at about latitude 37 degrees 41.8 minutes north and longitude 122 degrees 34.4 minutes west. This proposed diffuser location is slightly northwest

of that proposed in Volume I. The slight reorientation is deemed warranted since the total number of benthic organisms in the benthic surveys of the area was found to be highest at the previously proposed diffuser location. The currently proposed diffuser location will provide a somewhat greater margin of safety for the benthic organisms, as well as those fishes and invertebrates attracted to that area because of the relative availability of food. The proposed diffuser location is less than one-quarter mile east of Oceanographic Station 2.

The initial dilution which can be attained by the proposed dry weather diffuser during the fall oceanographic season (period of minimum stratification) was determined using the density profile at Station 2 on October 3, 1400 hours (Fig. 3-5) when there was the least density difference between top and bottom. The average of the northerly and southerly currents at Station 2 (Fig. 3-10) was assumed. The initial dilution analysis showed that at the peak rate of flow of 215 mgd, a dilution of about 100:1 would be attained in a stable field at a current velocity of 0.32 knots (K). The field would extend initially in the water column from depths of about 16 feet below the surface to about 35 feet below. Under the average dry weather flow of 125 mgd and a 0.32 K current, the initial dilution would be about 150:1 and the top of the field would be at a depth of about 18 feet. The average dry weather flow would achieve stability in the water column at a slightly lower level in the summer and winter seasons, based upon oceanographic data reported in Volume I. In each of the oceanographic seasons it is anticipated that most, if not all, of the dry weather effluent field will be entrained at or slightly above the pycnocline and be rapidly diluted beyond levels predicted for initial dilution.

Dilution at the dry weather diffuser is shown in Fig. 7-2 as a function of current velocity. At low current velocity the dilution becomes indeterminate by the Roberts formulae. Dilutions of 90 to 1 or greater would be attained at slack water according to Brooks (1960) and Ditmars (1969).

For a 785 mgd design flow wet weather discharge, the design criteria presented for wet weather disposal (Option 7B, described on pages 203 and 204 of Volume I) must be modified slightly. The submarine outfall pipe should have a 156-inch diameter with a total submarine length of about 8,400 feet to the eastern end of the diffuser section. The path of the wet weather outfall parallels that of the dry weather outfall as shown in Fig. 7-1. The diffuser section should have a length of 2,700 feet, oriented in the east-west direction with the shoreward terminus of the diffuser at latitude 37 degrees 42.8 minutes and longitude 122 degrees 31.9 minutes.

As previously noted, 92 percent of the wet weather occurs during the months when winter oceanographic season patterns prevail or would be induced by wet weather. Under these conditions the waters south of the San Francisco Bay are highly stratified with a shallow turbid surface layer which is rapidly advected seaward and a lower layer which has a slower net movement bayward. If rapid seaward movement of the wet weather effluent field is to be assured, a surface field is needed. It can be attained by a two-step initial dilution process. By using a relatively few large diameter ports, the column of effluent from each port will rise with sufficient velocity (4 to 6 feet per second) to reach the surface as a separate field and not resubmerge. First-stage dilution can not exceed 20 to 1 for this to occur. Because of the high vertical velocity, ocean currents would have little effect on first-stage dilution. The second stage of dilution would occur at the surface during initial buoyant spreading until the fields from each port merge to form a single wide field. This stage would occur within 15 minutes.

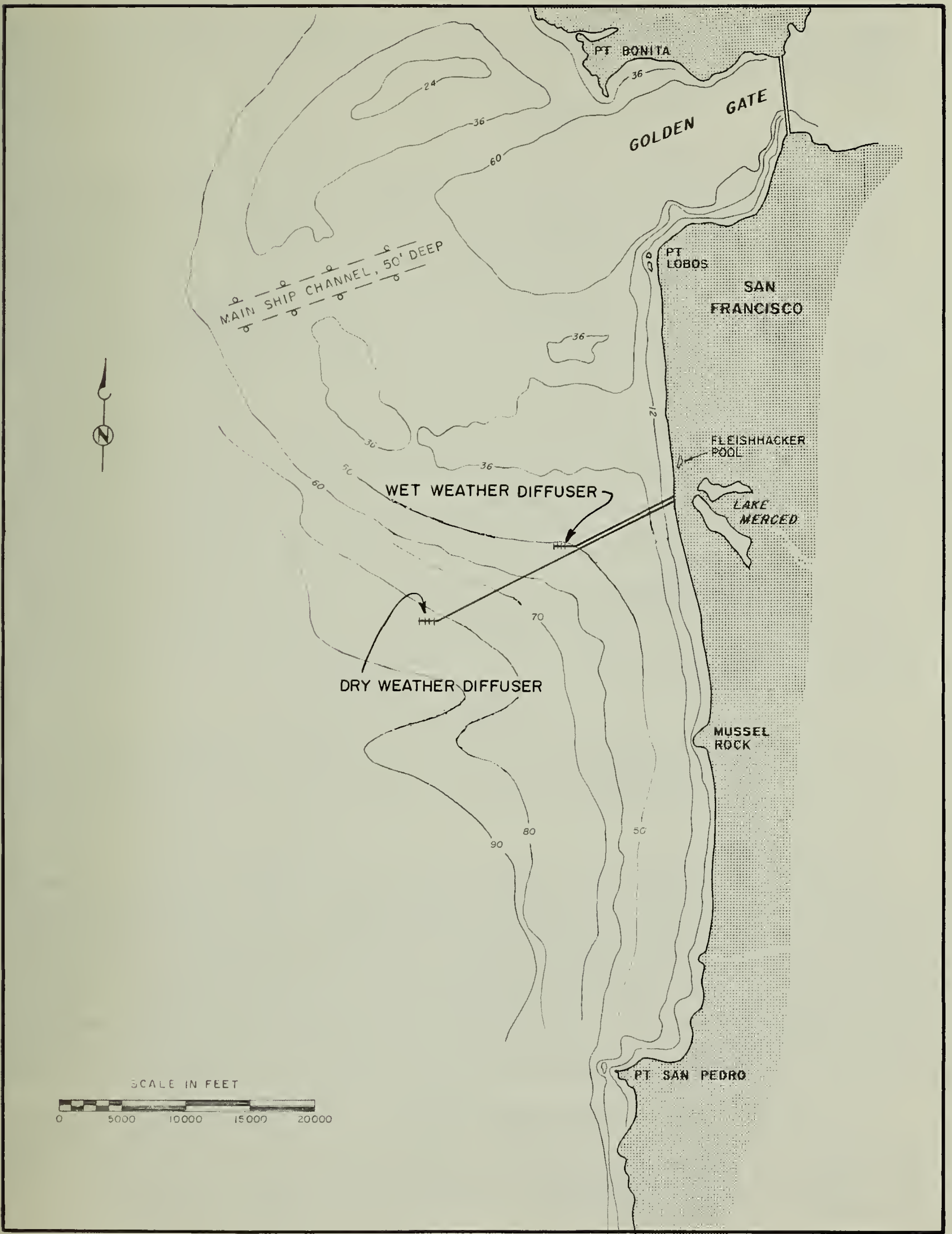


Fig. 7-1 Recommended Outfall

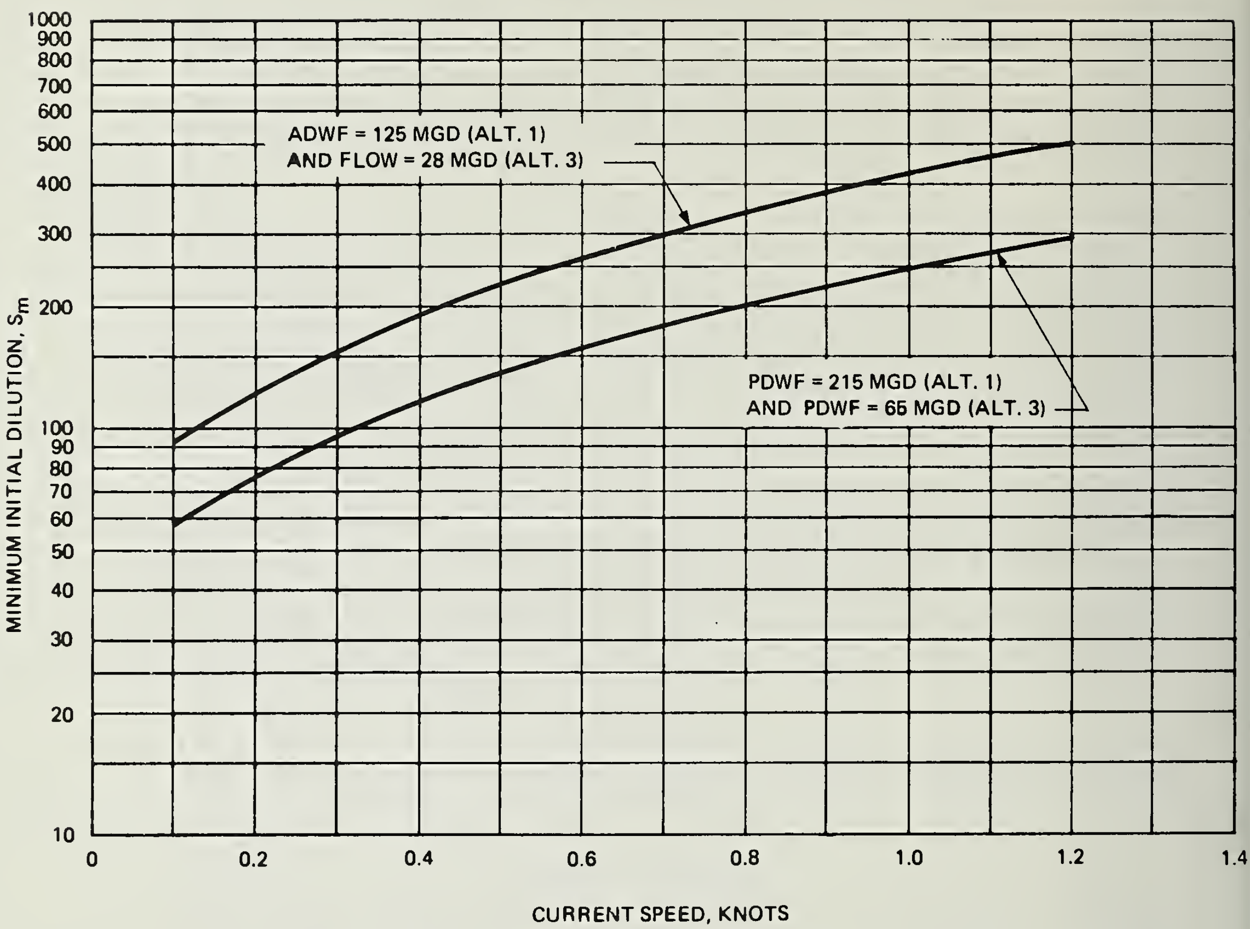


Fig. 7-2 Estimate of Initial Dilution, Dry Weather Flows to Ocean, Alternatives 1 and 3

A surface field could be found aesthetically objectionable after the few rains which may occur in October or early November when ocean turbidity is low and the winter outflow pattern has not become established. A subsurface field can be readily attained by using a larger number of smaller ports. As in the case of the dry weather flow, the Roberts formulae are appropriate to the alternative design. Because there are merits in each of these design concepts, we recommend that a dual set of ports be installed. Either set may be closed with blank flanges and both modes of operation can be tried to determine which is best under actual operating conditions. The cost of the additional ports is a minor element in outfall construction.

The design for a surface field will provide for a total of seventy-six 15.25-inch diameter ports at a spacing of 36 feet alternating on each side. They will be directed at an angle of 45 degrees above horizontal. We have assumed that the density pattern determined south of the bar at 1500 hours on February 3, 1970 (Volume II p. 5) is representative of winter conditions.

The large ports will provide a first-stage dilution in the center of the tip of the rising plume of 16 to 1 at peak flow of 785 mgd, and 21 to 1 at 300 mgd. The plumes would merge within six minutes which, in an average current velocity of 0.5 K, would be within a distance of 300 feet. Dilution upon merging would be 40 to 1 at peak flow and hence would more than meet the dilution ratio called for by an application factor of 0.1.

Ports for a subsurface field would be 6 inches in diameter, 226 in number at 12 feet spacing alternating on each side. Orientation would be at 45 degrees above the horizontal. The subsurface field would form between the depths of 5 and 14 feet. The relationship between current velocity and initial dilution is shown in Fig. 7-3. For a 0.5 K current, it would be 65 to 1 at peak flow and almost 200 to 1 at a flow of 250 mgd. A 0.5 K current is slower than the 0.76 to 1.2 K values observed in the turbidity bulbs in 1970. The slow current is assumed more typical of the water mass below the lower density surface lens.

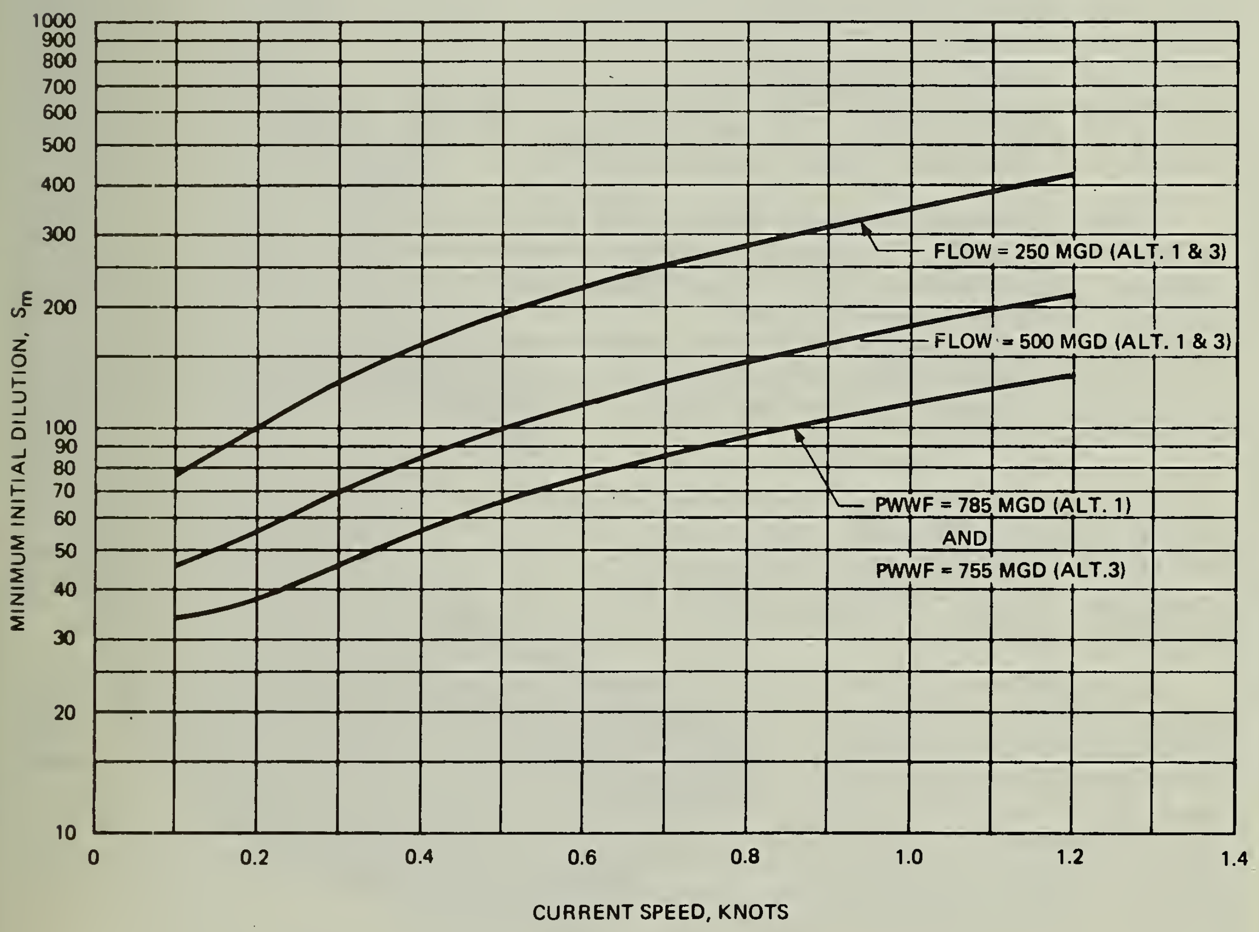


Fig. 7-3 Estimate of Initial Dilution, Wet Weather Flows to Ocean, Alternatives 1 and 3

For fall conditions the density pattern at Station 1 at 1400, October 2, 1973 (Fig. 3-4) is assumed along with average northerly and southerly currents of 0.3 K in the upper layer at that station (Fig. 3-4). The subsurface field would be similar to that in wet weather. The initial dilution at peak flow would be about 45 to 1 with higher dilutions at lesser flows (Fig. 7-3).

The estimated construction cost of the dry weather outfall is $29,500,000 and for the wet weather outfall, $31,900,000 at the 1975 contract cost level. These costs are based on the construction of separate pipe conduits for each outfall.

Preliminary Outfall Design for Effluent Disposal - Alternative 2

Effluent disposal Alternative 2 assumes discharge of all wet weather and dry weather flows to the bay in the vicinity of the Southeast plant. Sites available for submarine outfalls in the vicinity of Southeast WPCP site are extremely restricted because of maritime activity. Dredging is undertaken regularly in channels adjacent to the piers and docks and in the approach channel to Islais Creek. Offshore, the bay has a natural depth of about 50 feet but the entire area is laid out for ship anchorage and is heavily used for that purpose. As shown in Fig. 7-4, there are only two areas with minimal hazard from shipping and ship's anchors. The first is a triangular shaped area situated north of the Islais Creek approach channel. An inshore portion is the site of the present outfall. Water depth over the area is 35 feet at mean lower low water. The second is a similar area on the south side of the channel but with water depth ranging from 23 to 43 feet at mean lower low water.

The first site was examined and selected for the preliminary design of a dry weather outfall in 1973 for the purpose of establishing additional benthic monitoring stations. The maximum length of a diffuser approximately normal to the tidal currents would be about 2700 feet. The second area, south of the Islais Creek approach channel, could provide for a total length of outfall equal to the first site. However, most of this area contains shoals less than 30 feet deep and the remainder has a slope of about one foot per 100 feet, making it a less desirable location for a full 2700-foot diffuser.

For a dry weather outfall having a peak capacity of 215 mgd, the northerly site can be used for a 90-inch outfall extending 3700 feet from the pier bulkhaad. Of this length, 2700 feet would be the diffuser and would have six hundred seventy-six 2-inch horizontal ports situated alternately on each side of the pipe at 4-foot centers. Estimated contract cost of the submarine line is $4,820,000.

The outfall would have a port velocity of 23 fps at design peak flow and would, under conditions of little or no stratification, provide an estimated initial dilution of 180 to 1 at 0.6 K current and 300 to 1 at the design average flow of 125 mgd. Both would result in a surface field. The average current velocity of 0.6 K was computed from the USC and GS survey (1952-54) using two near-shore stations (Stations K and L, Volume II) in the vicinity of Islais Creek. A summary of initial dilutions as a function of current velocity is given in Fig. 7-5. As previously noted, the curves therein do not take into account initial dilution from dissipation of jet velocity and hence are not applicable at low current velocity.

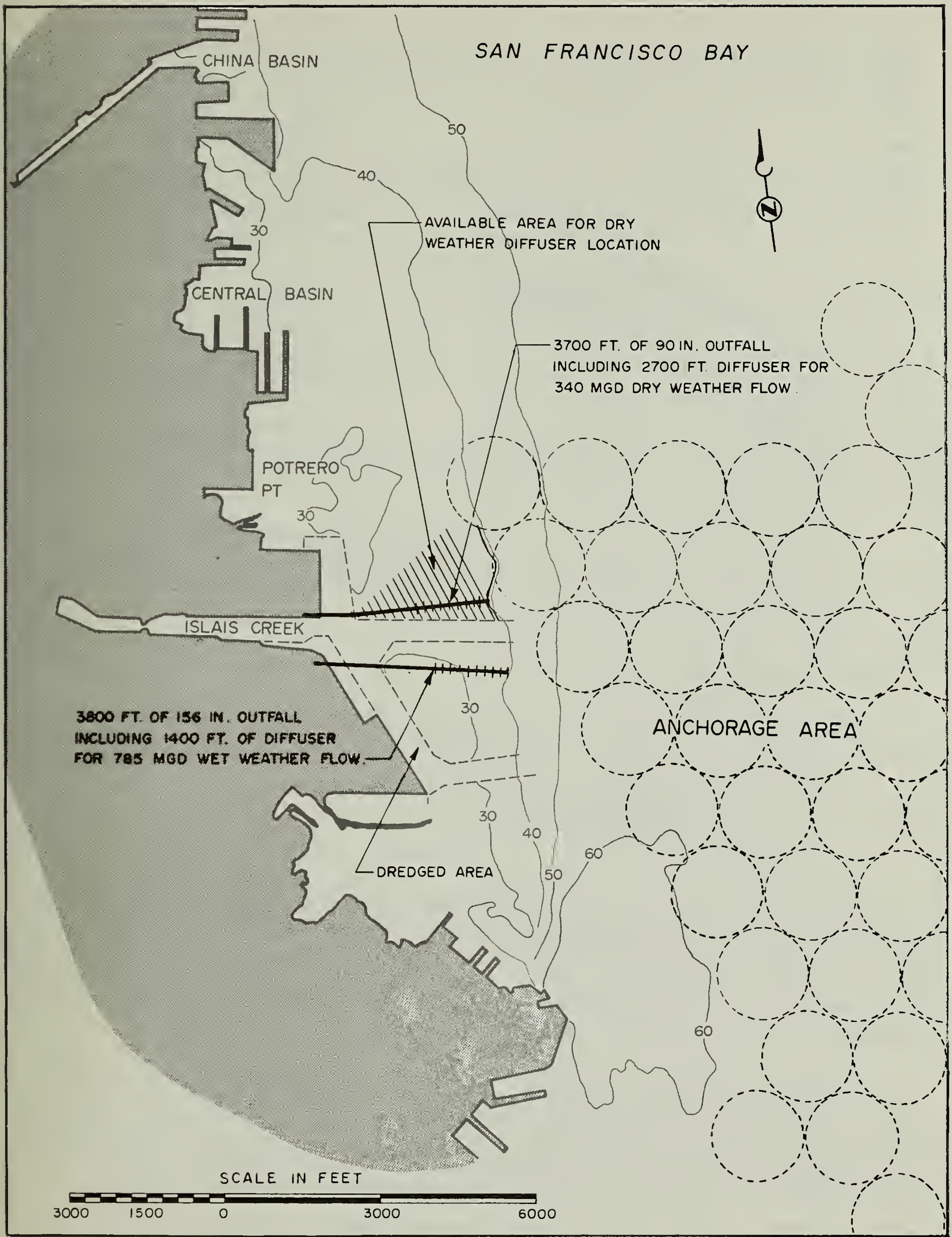


Fig. 7-4 Outfalls to Bay, Alternative 2

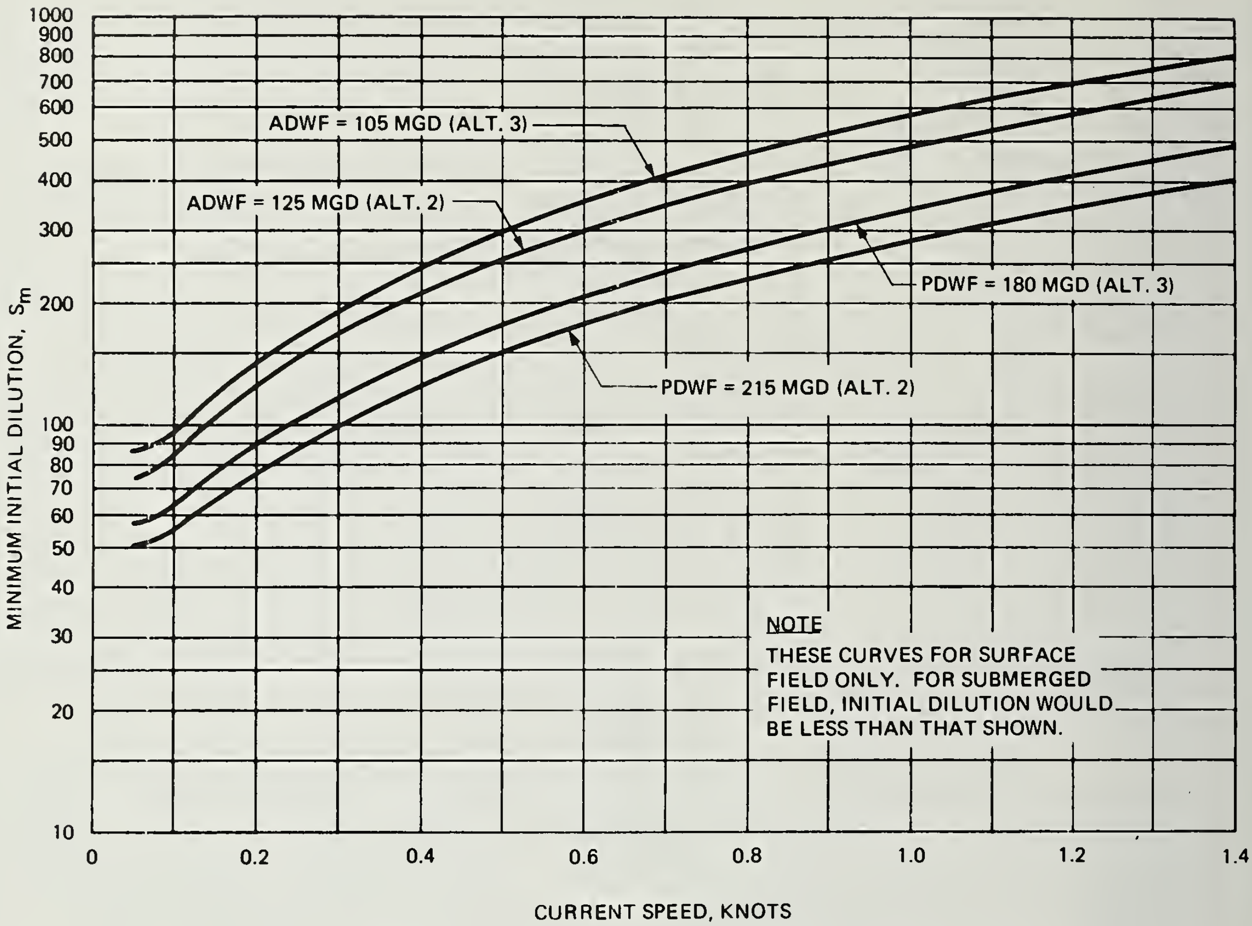


Fig. 7-5 Estimate of Initial Dilution, Dry Weather Flows to Bay, Alternatives 2 and 3

Under conditions of very low salinity such as occur during high Delta outflow to the bay, a salinity profile (such as shown in Volume II, page 75 for February 3, 1970) offshore from Pier 23 may also occur in the vicinity of Islais Creek. The density was only 1.0055 at the surface and 1.0150 at a depth of 35 feet. The corresponding salinity range was 8 to 22 parts per thousand. During a year of high outflow such a condition may persist for a period of two weeks to two months.

Under the foregoing low salinity condition, the dry weather diffuser jet would reach a density equilibrium with the bay water a short distance from the diffuser port and at a depth about two feet off the bottom. As a result, no further energy is left to cause it to rise. Such a field, diluted only to about 50 to 1, would tend to flow along the bottom and to disperse through diffusion and tidal action. Under these conditions, it should be noted, the flushing action in the bay is high.

For a wet weather outfall to the bay to carry a peak flow of 785 mgd, a diffuser at a depth of 35 feet could be constructed up to a length of about 1,400 feet. A location out of the path of the dry weather outfall would be desirable but does not appear feasible in the vicinity of Islais Creek. A location on the south side of the approach channel is assumed.

The wet weather outfall should be about 156 inches in diameter and have a total submarine length of 3,800 feet. The 1,400-foot diffuser section would have 18-inch ports at a 45 degree angle above the horizontal and at 60-foot centers, alternating on each side of the pipe. Estimated construction cost is $10,900,000.

For this design, and peak wet weather flows, a surface field would be achieved at an initial dilution of about 30 to 1 under all but the most adverse of water density gradients. With surface fields and 250 mgd and 500 mgd flows, dilutions estimated at 80 to 1 and 45 to 1 would be realized. Figure 7-6 shows dilutions of wet weather flows at a wide range of current velocities.

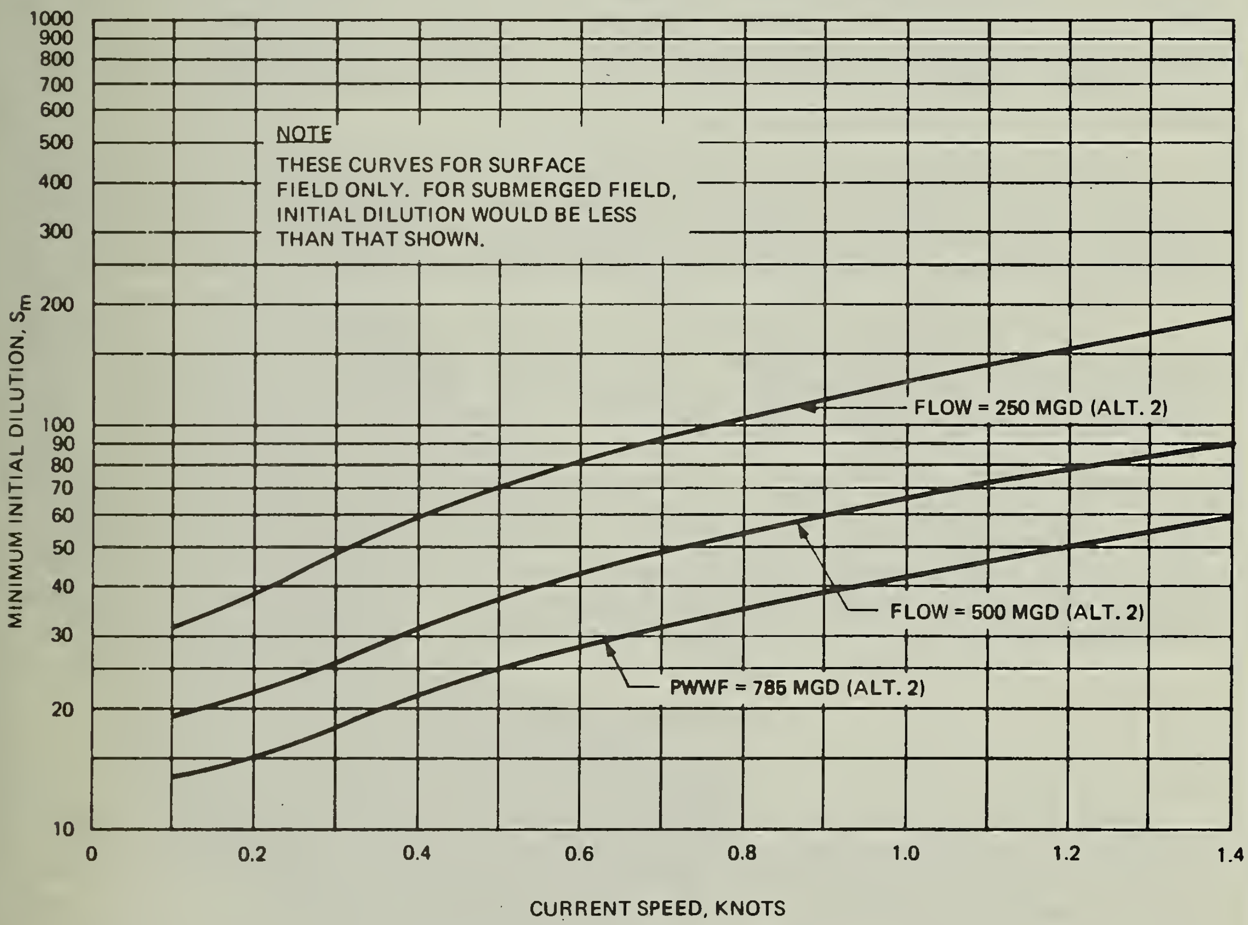


Fig. 7-6 Estimate of Initial Dilution, Wet Weather Flows to Bay, Alternative 2

Under the low salinity condition previously described, the wet weather field would reach stability within a few feet of the bottom at a peak flow initial dilution of 10 to 1.

The wet weather and dry weather fields would tend to overlap and the overall combined dilution would be slightly less than that noted above for the separate discharges. Such a condition would be most adverse when the effluent fields form near the bottom, since dilution is least under that condition.

Preliminary Outfall Design for Effluent Disposal - Alternative 3

Effluent disposal Alternative 3 assumes discharge of all wet weather flow to the ocean as well as dry weather flow generated in the Richmond-Sunset tributary area. Dry weather flow generated in the North Point and Southeast tributary zones would be treated and discharged at the Southeast WPCP. Figure 7-7 shows the proposed outfall and diffuser orientation for the dry weather discharge at Southeast. Figure 7-1 shows the location of the wet and dry weather outfalls and diffusers for ocean disposal for Alternative 3.

The peak dry weather flow of 65 mgd discharged to the ocean would require an outfall and diffuser diameter of 51 inches and a diffuser length of about 375 feet. Diffuser ports should be 3.5-inch diameter spaced at 6-foot intervals, situated alternately on opposite sides of the diffuser. Estimated construction cost is $17,600,000. Under these conditions, diffuser performance would be similar to the design for the dry weather diffuser, Alternative 1.

The peak wet weather flow of 755 mgd discharged to the ocean would require an ocean outfall and diffuser essentially as discussed for Alternative 1, except that the diffuser length would be reduced to 2,600 feet. Construction cost likewise would be essentially the same. Performance would be similar to that described for Alternative 1.

The 180 mgd peak dry weather flow to the bay would require an outfall and diffuser of about 84-inch diameter. The diffuser length of 2,700 feet would remain unchanged from that recommended in Alternative 2. Diffuser ports would be 2-inch diameter, situated alternately on opposite sides of the pipe at 5-foot centers.

Under conditions of little or no stratification and an average current velocity of 0.6 K, the dry weather diffuser in the bay would provide an estimated dilution of 210 to 1 at peak flows (180 mgd) and 350 to 1 at flows of 105 mgd. In both cases, a surface field would result. Under conditions of low surface layer density, the dry weather diffuser jet would reach stability in the field at a depth of only a few feet off the bottom. Under such conditions, initial dilution is estimated to be about 60 to 1.

EFFLUENT DISPERSION

Initial dilution, buoyant spreading and subsequent dilution are all sequential elements in the overall phenomenon of effluent dispersion. Initial dilution and buoyant spreading concepts developed recently by Roberts (1975) have been used and discussed previously in the design and prediction of performance of dry and wet weather diffusers. This section discusses the basis for estimating subsequent dilution of an effluent field and presents in graphic form overall dispersion patterns under assumed conditions for dry and wet weather effluent disposal to the ocean as envisioned in Alternative 1. Dispersion estimates for disposal alternatives which involve bay effluent discharge are not shown since the complexity of the current regimes in the bay, the limited amount of data available in the vicinity of the proposed discharges, and the proximity to shallow water and shoreline boundaries limit the applicability of the subsequent dilution model.

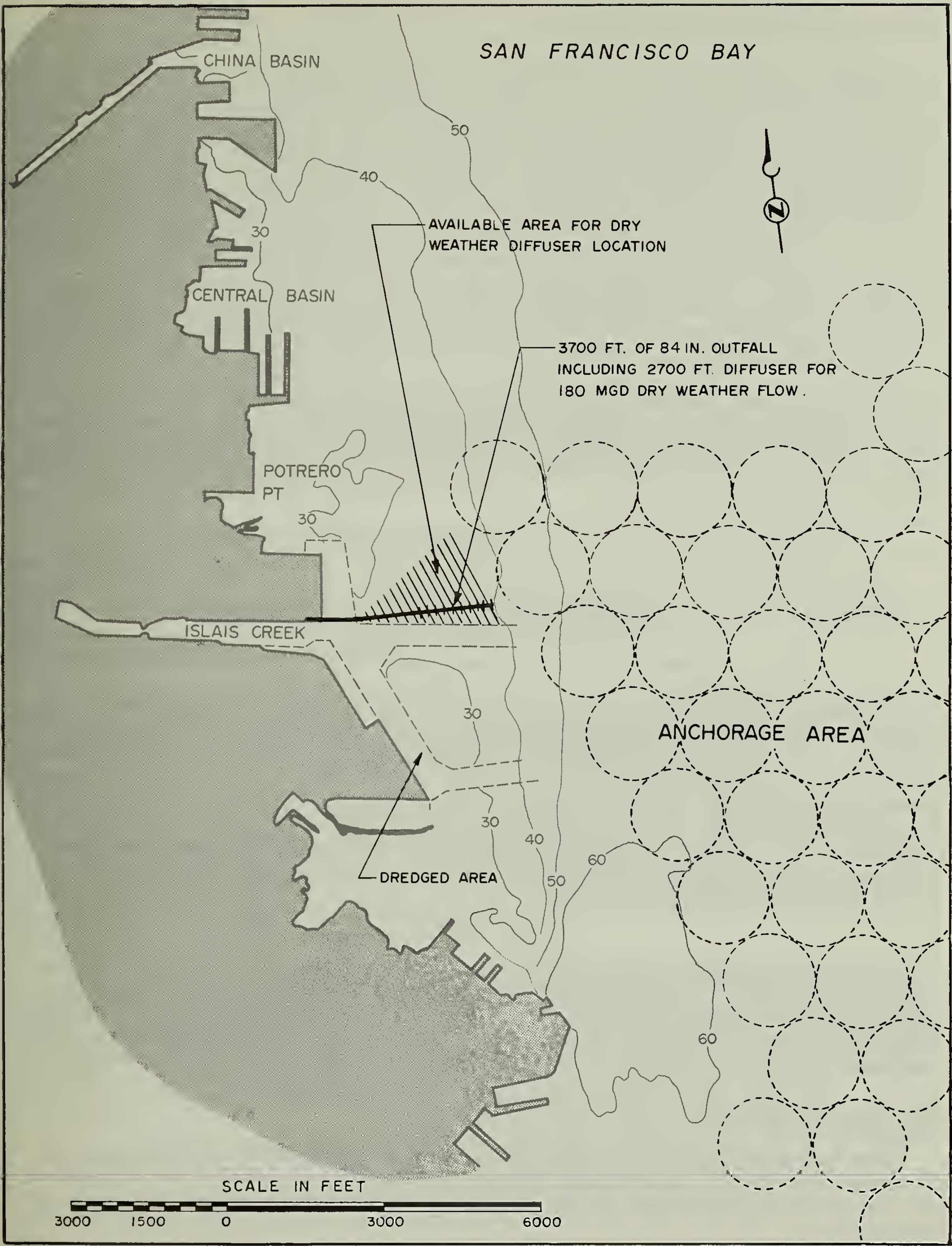


Fig. 7-7 Outfall to Bay, Alternative 3

Basis of Subsequent Dilution Model

Following initial dilution and buoyant spreading of the effluent field to its equilibrium position in the water column, whether submerged or as a surface layer, the effluent-seawater mixture is subject to further dispersion forces because of natural ocean turbulence. This phenomenon is known as subsequent dilution. Subsequent dilution results from the turbulent diffusion of the effluent into the ambient ocean waters as the effluent is advected away from the outfall site by currents. Except in unusual cases where strong vertical currents exist, diffusion is much greater in the horizontal direction than in the vertical direction. Hence, the area of a diluting effluent field increases much faster than its thickness. Compared with the very rapid initial dilution attained by the turbulent jet and buoyancy action, subsequent dilution to attain a further reduction in effluent concentration is a relatively slow process, often requiring many hours to reach a level of one-tenth the initial dilution.

Pearson (1956) showed that horizontal turbulent diffusion in ocean waters is approximated by Richardson's law, more commonly referred to as the "four-thirds law". The four-thirds law defines the coefficient of turbulent diffusion, which relates the rate of horizontal diffusion to the dimensional scale or width of the field raised to the four-thirds power:

$$E = \alpha L^{4/3}$$

where: E = turbulent diffusion or dispersion coefficient,
α = four-thirds law coefficient, and
L = scale or width of the sewage field.

For the case where the scale of the field is taken as 2-sigma (where sigma is the standard deviation of the concentration distribution in a direction perpendicular to the axis of travel), Pearson demonstrated that measured ocean horizontal turbulent diffusion data are well approximated by taking to be about 3.6 $ft^{2/3}$/hr. However, Pearson also notes that may vary from a minimum of about 2.1 $ft^{2/3}$/ hr to a maximum of about 29.5 $ft^{2/3}$/hr. Dye dispersion studies conducted within the Gulf of the Farallones in the winter, summer and fall of 1970 (Volume I) showed that lateral dispersion within this area is well approximated by the above four-thirds law, with an of about 20 $ft^{2/3}$/hr for $L = 2\sigma$.

Brooks (1960) provided analytical solutions for the case of subsequent dilution where vertical and longitudinal turbulent diffusion are assumed negligible and where horizontal turbulent diffusion is defined by the four-thirds law. Brooks defines the scale of the field at $2\sqrt{3}\sigma$. Thus, to equate Pearson's dispersion coefficient (E), with Brooks', Pearson's α value is multiplied by a factor of 0.48.

Results of Subsequent Dilution Modeling

Using Brooks' formulations and the results of the initial dilution calculations discussed previously, subsequent dilution estimates were made for wet weather and dry weather discharges in the Gulf of the Farallones for wastewater disposal Alternative 1.

In order to present the results in graphic form, assumptions are necessary with respect to volume of flow, current velocity and direction. It is assumed that each of these independent variables is constant for the period of time necessary to develop a defined plume, as for example, in Fig. 7-8 and 7-9. For the 0.32 K current there shown, the plume delineated at a dilution of 200 to 1 would require 8.5 hours to develop. During that period, as evidenced by Fig. 3-10, current direction at the diffuser site would have changed continuously in a generally clockwise direction over a total angle of more than 90 degrees. The current velocity, moreover, may have varied over a range of 0.15 to 0.7 K. For this reason the dispersion patterns here shown are highly simplified. They can be taken to represent the gross area occupied by a field of a given dilution but not its shape nor its location.

Fall Season. Subsequent dilution of dry weather discharges during the fall oceanographic season is estimated in Fig. 7-8 through 7-12. The estimates were developed based upon both peak (215 mgd) and average (125 mgd) dry weather flows and average northerly and southerly current vectors at Station 2, discussed in Chapter 3 (Fig. 3-10). Actually, the "average" northerly and southerly currents were measured during a 25-hour tidal cycle of moderately low amplitude; thus, fall season dispersion curves may be assumed to be somewhat conservative from the standpoint of the true "average" fall current condition and may more appropriately be considered to be "design" current velocities.

Figure 7-8 shows the estimated subsequent dilution at peak dry weather flows and southerly current velocity of 0.32 K. A dilution of 100 to 1 is reached in the field following initial dilution. Buoyant spreading of this effluent field is the predominant force influencing the shape of the dispersion curve for a distance of about one nautical mile downcurrent. Dilution to 200 to 1 would be accomplished about 3 nautical miles downcurrent.

A schematic of the subsequent dilution in the vertical plane along the centerline of the effluent field is given in Fig. 7-9. The idealized field is shown to have an initial thickness of 19 feet with a thickness following buoyant spreading of about 4 feet. Vertical dispersion also occurs at a slow rate but is not shown.

Estimates of subsequent dilution for average dry weather flow and average northerly and southerly fall season current vectors are presented in Fig. 7-10 and 7-11. Note that in each case, an initial dilution of about 150 to 1 is followed by subsequent dilution to 200 to 1 within less than two nautical miles downcurrent. Figure 7-12 is a schematic of dilutions along a vertical section for the average dry weather flow and average northerly current speed.

Summer Season. Subsequent dilutions of dry weather discharge during the summer oceanographic season are given in Fig. 7-14 and 7-15. Current velocities for this period are assumed to be the same as those measured at Station Y, June 17-18, 1971 (Volume II, p. 50-51). In both cases, initial dilutions exceed that required for an application factor of 0.1 by a factor of 15 or more. An effluent dilution of 200 to 1 in the water column is reached less than two nautical miles downcurrent.

Winter Season. Estimates of subsequent dilution of dry weather and wet weather discharges which occur during the winter oceanographic season are shown in Fig. 7-15 and 7-16. Current velocities for the winter oceanographic season were selected based upon criteria discussed previously for the Alternative 1 outfall design.

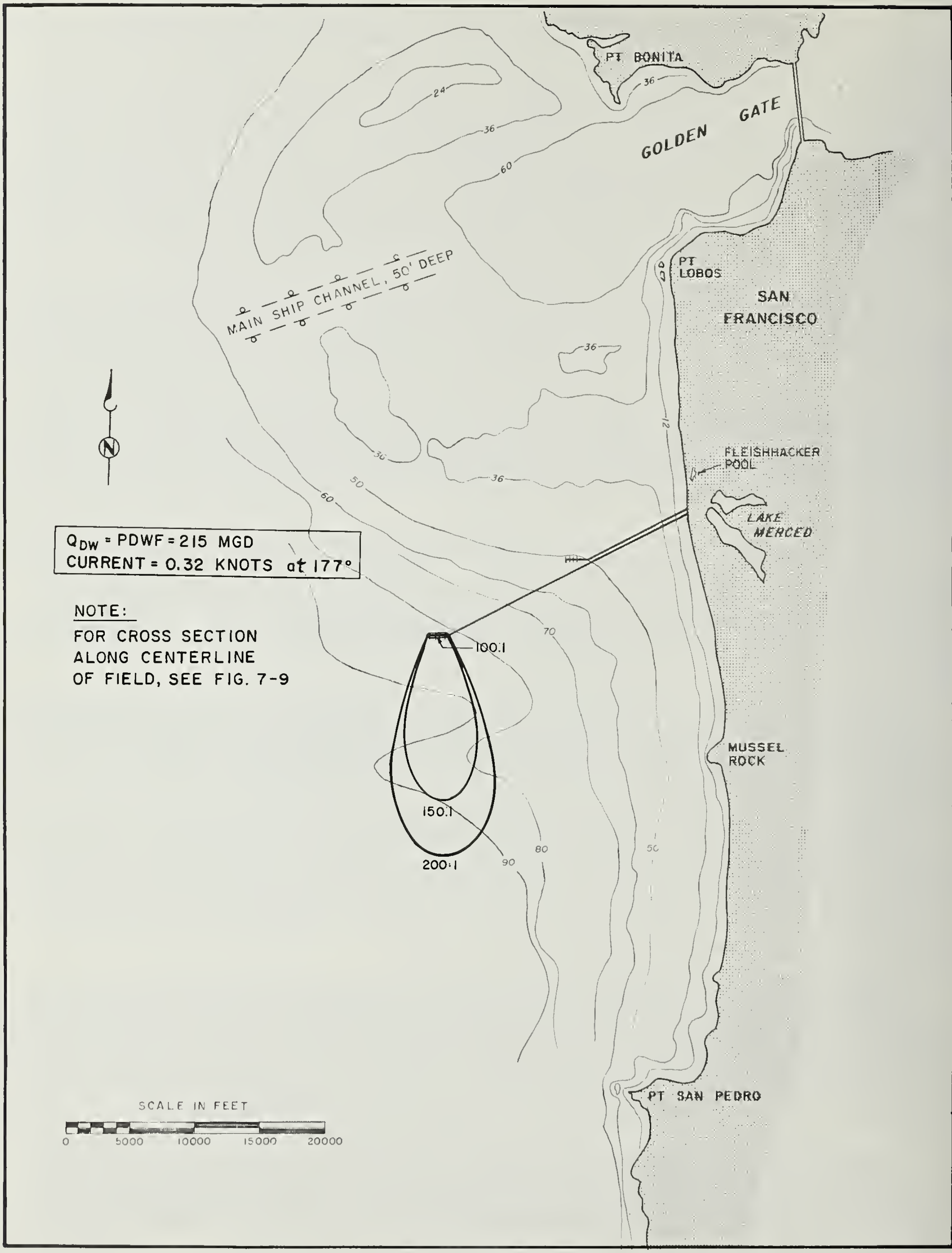


Fig. 7-8 Estimated Dilution after Rise of Effluent to Upper Water Layer, Fall Season, Peak Dry Weather Flow, Average Southerly Current Velocity

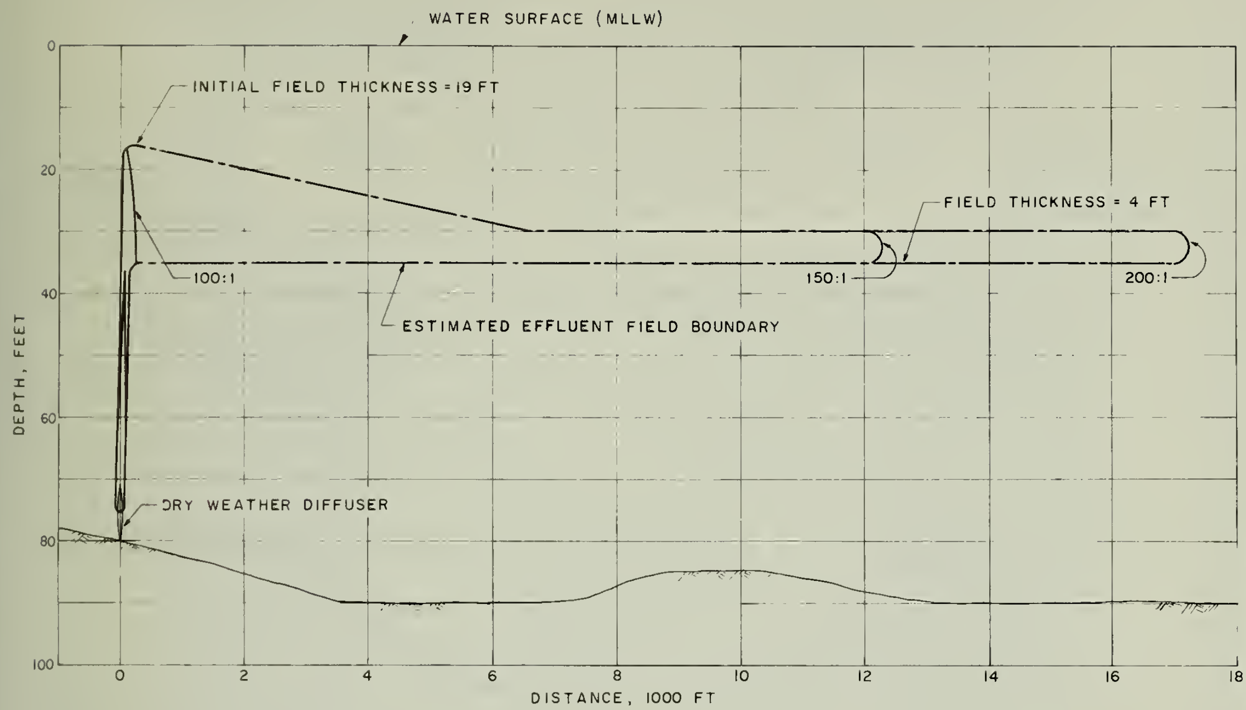


Fig. 7-9 Estimated Dilution Along Centerline of Effluent Field, Fall Season, Peak Dry Weather Flow

Initial dilution of about 260 to 1 is expected for the dry weather flow under average conditions in the winter. The initial dilution of the dry weather flows provides effluent concentrations a more dilute than called for from biological testing. The high initial dilution for dry weather flow will result in an effluent field with density characteristics that will cause it to reach equilibrium in the water column in the vicinity of the pycnocline. Since the pycnocline represents the transition zone between the lower density surface layer and higher density bottom layer, subsequent dilution of this effluent would result in very dilute effluent concentrations in both the upper and lower layers. That fraction of the effluent entrained in the surface layer would be advected seaward in a generally southerly direction. That effluent portion entrained in the lower layer could be carried with the more dense water mass into the bay. However, it should be noted that during tidal conditions conducive to carrying very dilute concentrations of effluent into the bay, the amount of effluent contained in the tidal exchange flow would be insignificant.

The operation of the wet weather diffuser with the large ports open would result in an initial surface field having a dilution of 40 to 1 at peak flow. Subsequent dilution to 100 to 1 would occur in about 3.5 hours at a distance downcurrent of about 8,000 feet in the fall season and less than two nautical miles downcurrent in the winter oceanographic seasons. With the small ports open, initial dilution in a subsurface field would occur at an initial dilution of 50 to 1 in the fall and 65 to 1 in the winter season. Subsequent dilution to 100 to 1 would occur in about 7 hours.

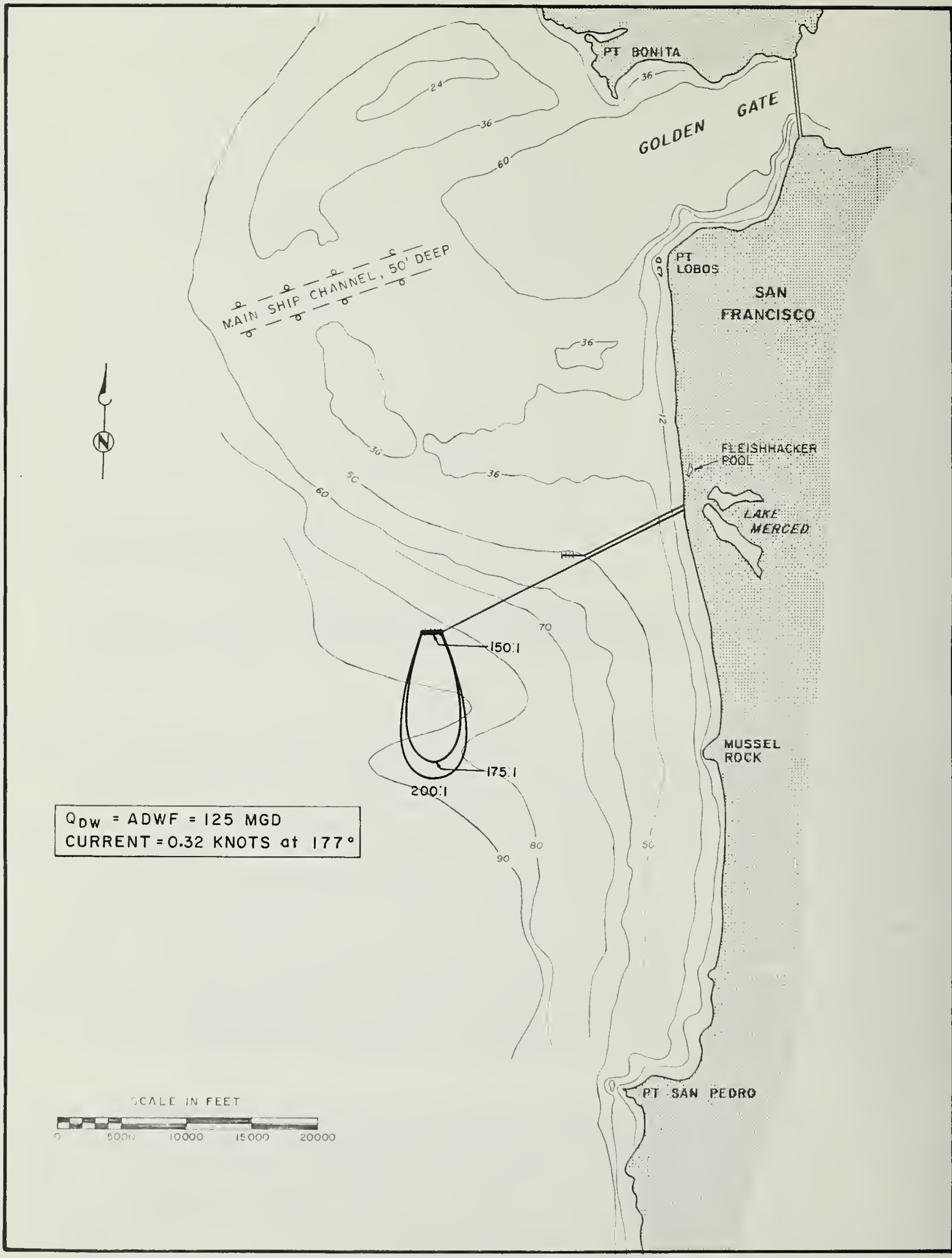


Fig. 7-10 Estimated Dilution after Rise of Effluent to Upper Water Layer, Fall Season, Average Dry Weather Flow, Average Southerly Current Velocity

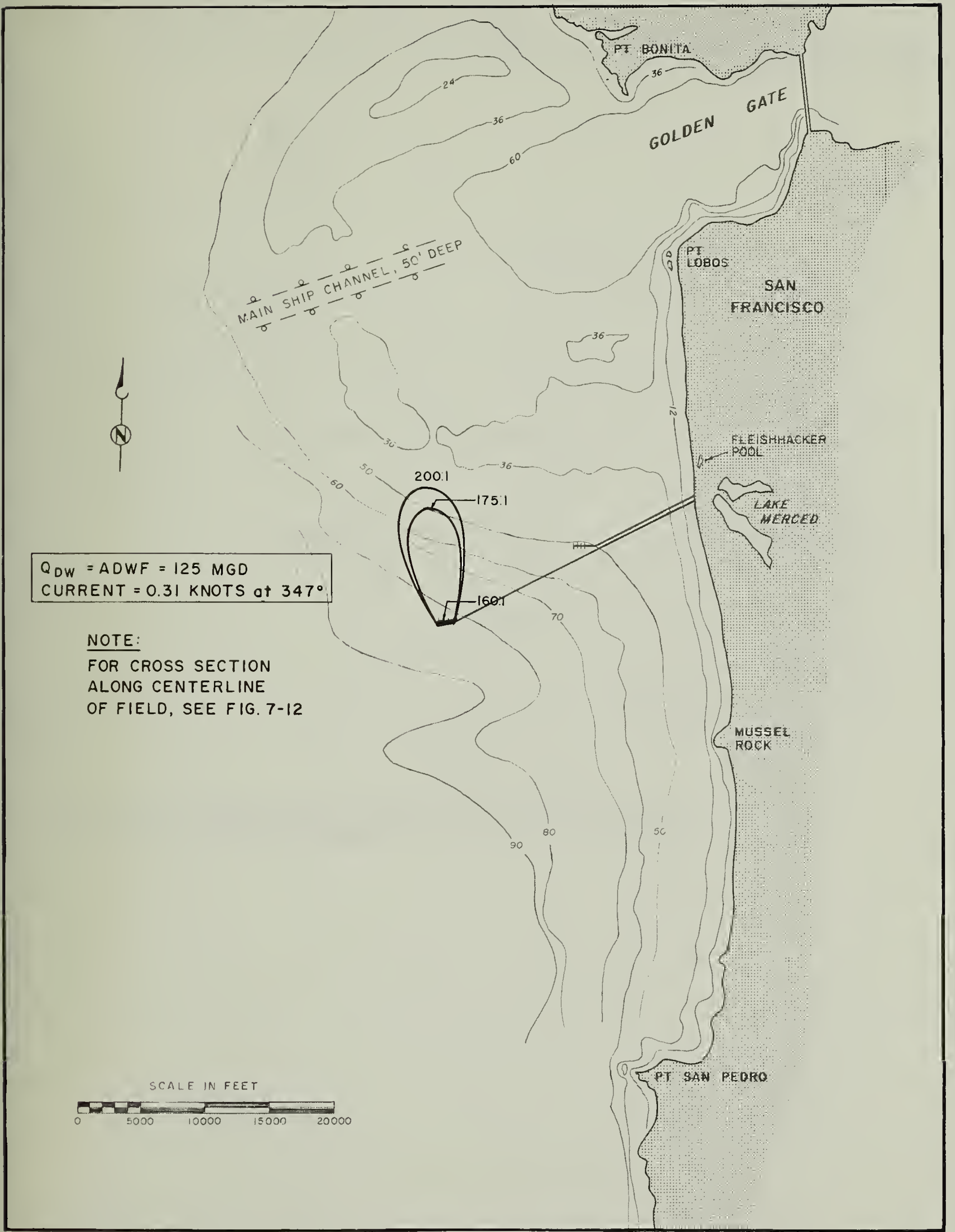


Fig. 7-11 Estimated Dilution After Rise of Effluent to Upper Water Layer, Fall Season, Average Dry Weather Flow, Average Northerly Current Velocity

Fig. 7-16 indicates the area which might be occupied by the wet weather plume under the assumptions of continuous peak flow, continuous and average current and current direction.

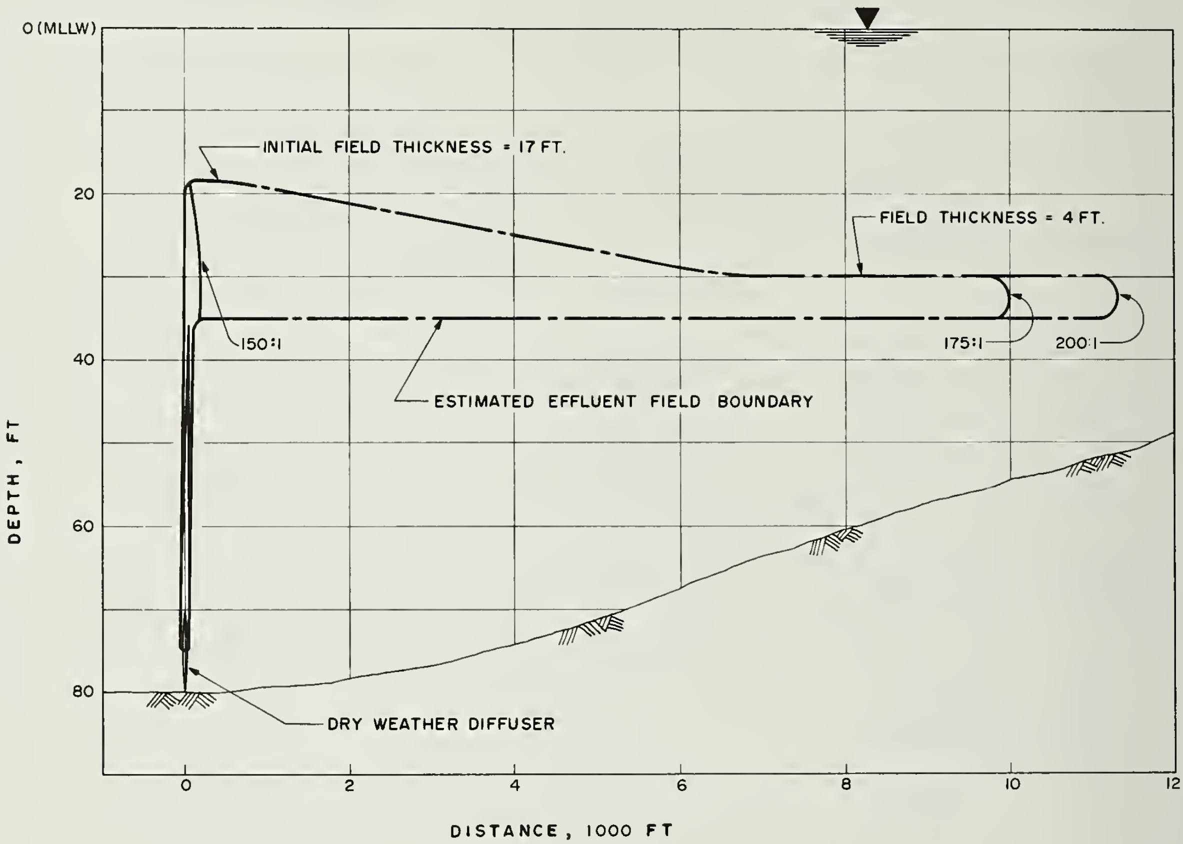


Fig. 7-12 Estimated Dilution Along Centerline of Effluent Field, Fall Season, Average Dry Weather Flow

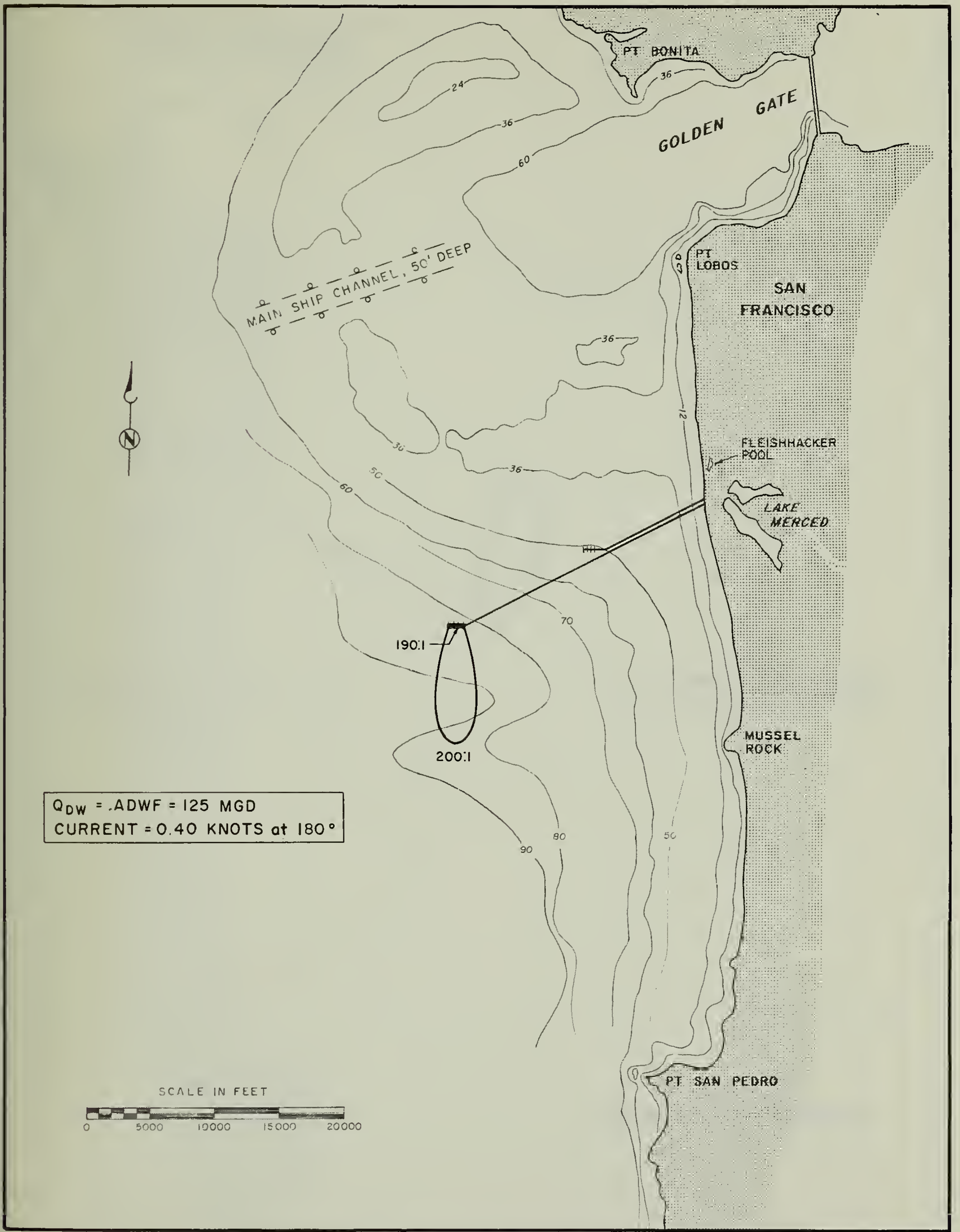


Fig. 7-13 Estimated Dilution after Rise of Effluent to Upper Water Layer, Summer Season, Average Dry Weather Flow, Average Southerly Current Velocity

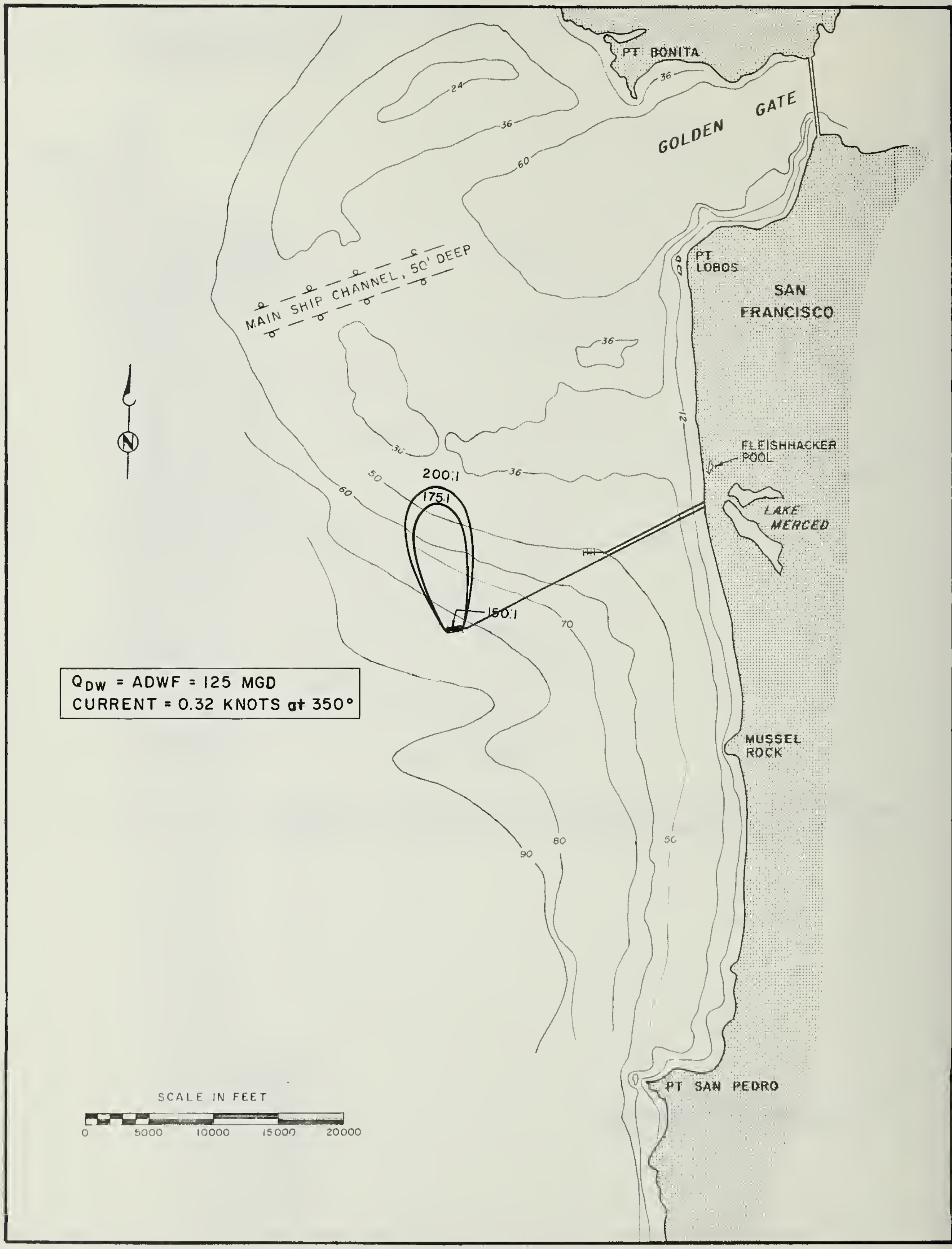


Fig. 7-14 Estimated Dilution after Rise of Effluent to Upper Water Layer, Summer Season, Average Dry Weather Flow, Average Northerly Current Velocity

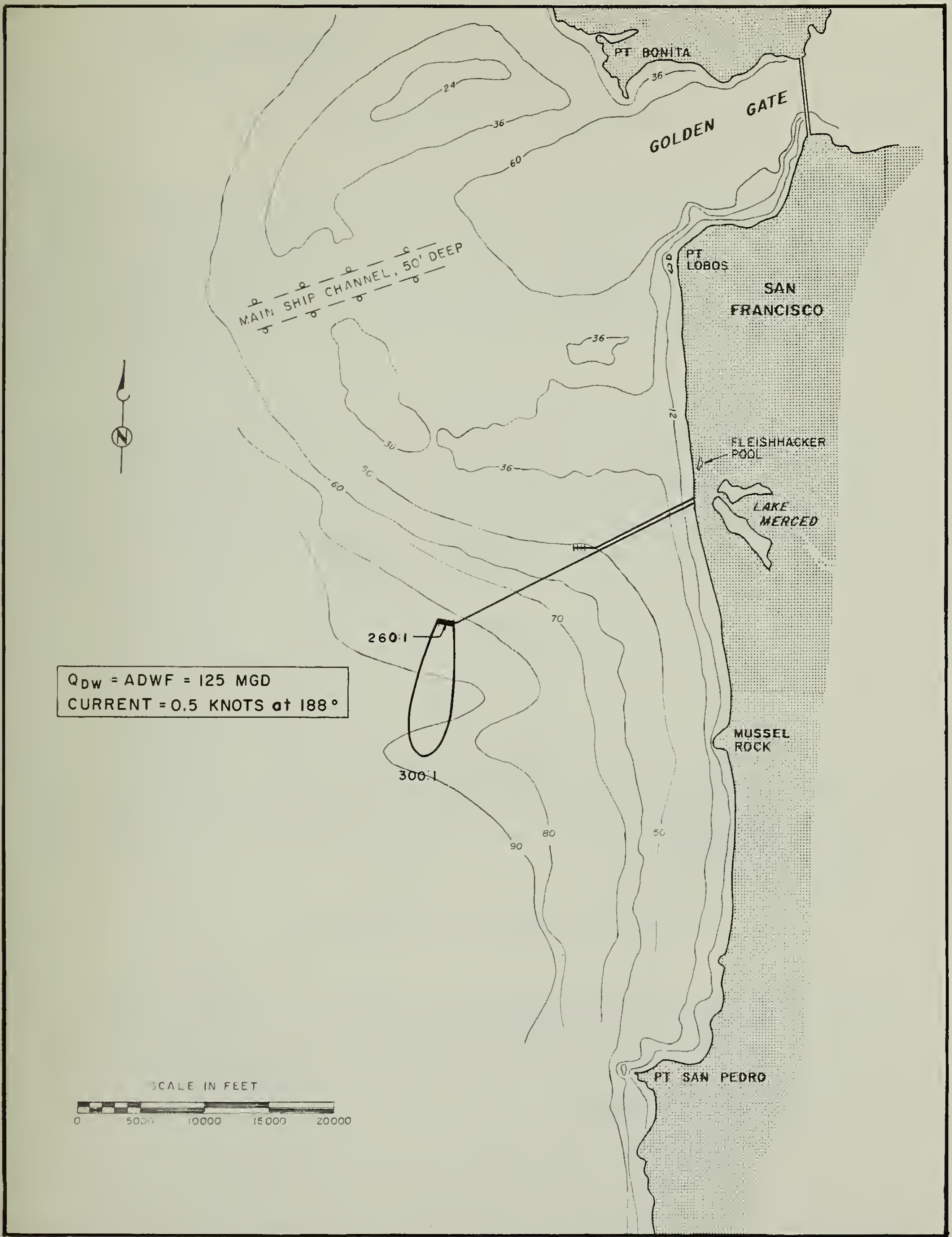


Fig. 7-15 Estimated Dilution after Rise of Effluent to Upper Water Layer, Winter Season, Average Dry Weather Flow, Average Southerly Current Velocity

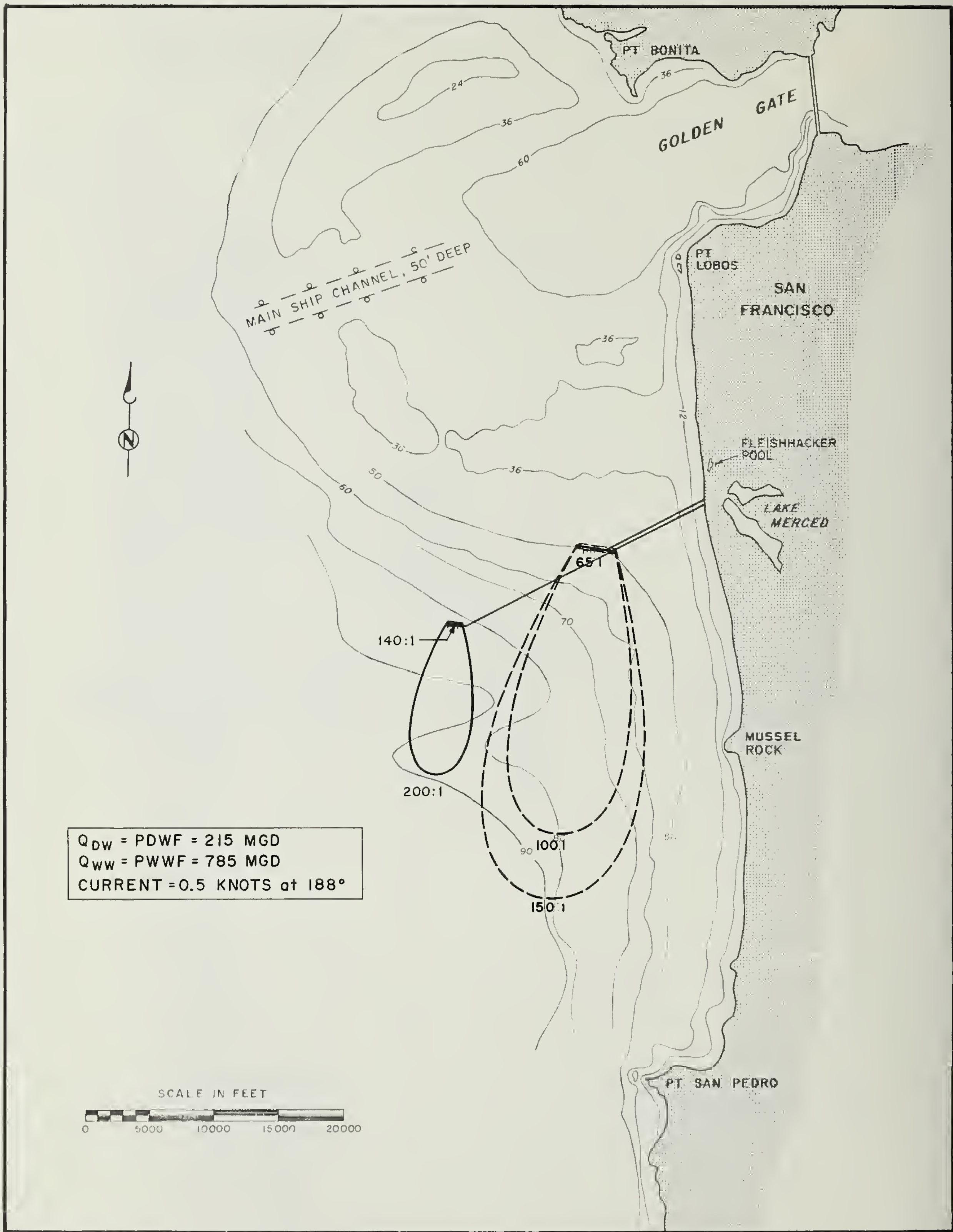


Fig. 7-16 Estimated Dilution after Rise of Effluent to Upper Water Layer, Winter Season, Peak Dry Weather Flow, Peak Wet Weather Flow, Average Southerly Current Velocity

CHAPTER 8

COMPARISON OF ALTERNATIVES

Three alternative disposal schemes were presented in Chapter 7, namely: (1) provision of outfalls for direct disposal to the ocean of dry and wet weather effluent from the entire city; (2) provision of outfalls to the bay for disposal of dry and wet weather effluent from the entire city; and (3) provision of an outfall to the bay for disposal of dry weather effluent from the North Point and Southeast service areas, and an outfall to the ocean for disposal of dry weather effluent flows from the Richmond-Sunset service area and wet weather effluent from the entire city.

Typically, a comparison of alternatives which are designed to achieve essentially equal or adequate results considers first the estimated costs and second other factors which cannot readily be converted to cost. In this case, the submarine outfalls are only a part of the facilities required for each alternative. Hence, a comparison can be made only after incorporation of the estimates of cost of the submarine outfalls with those of all other facilities for each of the alternative plans. With this in mind, the preliminary estimates of cost for the submarine outfalls only may be summarized as follows:

Alternative 1, $61,400,000

Alternative 2, $15,720,000

Alternative 3, $62,600,000.

The alternatives can be compared qualitatively with respect to protection of marine organisms, protection of public health, risk of damage to an outfall, and with respect to the likelihood that a change in effluent standards will occur which will require more treatment than is now planned. The apparent best alternative is designated.

PROTECTION OF MARINE ORGANISMS

Marine organisms are shielded most from effects of an effluent, whether beneficial or adverse, by a form of disposal which will minimize the opportunity for exposure of the organisms to effluent constituents at any concentration. In that respect, the disposal of wastewater to the ocean in Alternative 1 is superior to disposal to the bay in Alternatives 2 and 3. Effluent discharged from the ocean outfall will generally rise above the ocean floor without contacting bottom organisms or sediments. Also, the daily net seaward advection of effluent achieved with ocean disposal will minimize exposure of organisms and sediments in near-shore shallow waters to wastewater. The field which forms when effluent is discharged to the bay in Alternatives 2 and 3 will often contact the shoreline and the organisms and sediments in those waters. Also, during a year with high flow of freshwater into the bay, the effluent field that will form in the bay in Alternatives 2 and 3 will at times be carried from the disposal area at an elevation close to the bay bottom,

allowing great opportunity for effluent constituents to contact sediments and bottom organisms at low dilutions. Bottom organisms in the bay could be contacted by a dry weather effluent field at dilutions as low as 50 to 1 and by a wet weather field at dilutions as low as 10 to 1. If Dungeness crab larvae are carried into the bay as surmised (see Appendix G), the latter dilution may provide but little safety factor against adverse effects found in the toxicity studies.

An additional factor that will allow greater protection of marine organisms with ocean disposal than will be provided with bay disposal is the absence of other major discharges of effluent near the proposed ocean disposal site. The bay receives many major discharges of effluent. Thus, the background toxicity level in the bay as a whole will be greater than the level directly upcurrent from the ocean disposal site. For this reason, disposal of San Francisco's effluent directly to the ocean will be less likely to cause toxicity critical to marine organisms.

PROTECTION OF PUBLIC HEALTH

An axiom of public health has been the principle of physically separating disease vectors from people. This is particularly important when considering food sources. For this reason, the Water Quality Policy for Enclosed Bays and Estuaries states that discharges shall not be made into or adjacent to areas where the protection of beneficial uses requires spatial separation from waste fields. In particular, such areas are those used for shellfish harvesting and for public bathing beaches.

Although the bay disposal site is not within or immediately adjacent to areas which now require spatial separation, the fact remains that the effluent fields would usually be at the surface and could come in contact with the shoreline. Further, edible species of shellfish do occur in the bay and large numbers of people use the bay for work and recreation. In contrast, the discharges to the ocean are offshore and will move seaward. Few people utilize the area affected by the discharges, and the dry weather effluent field will remain submerged. For these reasons, at times when the effluent might be a hazard to public health, such as during a treatment failure, effluent disposal entirely to the ocean (Alternative 1) is inherently superior to disposal to the bay under Alternatives 2 and 3.

RISK OF DAMAGE TO OUTFALL

If an outfall is damaged so that wastewater is discharged from a break rather than from the diffuser, a surface field having a low dilution will form. Depending upon the extent of damage the effluent may not meet the dilution needed for adequate protection of marine biota until the break is repaired. The alternatives differ with respect to risk of damage to an outfall by maritime activity or by a major earthquake.

The ocean outfall will be out of the way of shipping channels and at sufficient depth to avoid navigation hazards. In contrast, outfalls which would be provided in the bay in Alternatives 2 and 3 would be in a shallow area surrounded by dredged channels and anchorage areas. The not uncommon practice of anchor dragging is a threat to the integrity of any outfalls in such bay areas.

The ocean outfall would be susceptible to damage as a result of a large movement at the San Andreas Fault. In that situation, wastewater would likely be discharged to the ocean at the location of the fault, about 7,000 feet offshore. The wastewater would reach the surface of the receiving waters after attaining a dilution of about 4 to 1, and would receive further dilution as it moves horizontally in a surface field from the discharge area. That situation would last until repairs are completed. Up to one year may be needed for that work.

Factors discussed above which provide greater protection of marine organisms and health with ocean disposal than with bay disposal will be operative also if an outfall is broken. Since the most likely location of a break in an outfall would be substantially further from shore with ocean disposal in Alternative 1 than with bay disposal, Alternative 1 will provide superior protection.

SUSCEPTIBILITY TO UPGRADING OF STANDARDS

Effluent quality requirements for discharge to the bay and the ocean are now essentially the same. Possible changes in these requirements would likely take one of three forms: (1) the bay discharge requirements will become more stringent, (2) the ocean requirements will become less stringent, or (3) both changes could occur. The possibility that any of these changes could occur favors the choice of ocean disposal over disposal to the bay. An example of a policy which may be adopted and which would require more treatment for bay discharges than for ocean discharges is the goal expressed in the State Water Resources Control Board's Water Quality Control Plan, San Francisco Bay Basin, that the quality of bay waters be improved to permit the harvesting of shellfish for human consumption. An area designated for such use in the tentative plan is just south of Candlestick Park. If such use becomes policy, it is likely that treatment facilities would have to be improved to assure a very high degree of disinfection with virtually no possibility of failure to meet bacteriological standards. Such a policy would require filtration, an additional treatment process not now planned.

APPARENT BEST ALTERNATIVE

Disposal of wastewater to the ocean as in Alternative 1 is superior to disposal to the bay as in Alternative 2, and to disposal to the bay and ocean as in Alternative 3. This superiority lies in better protection of marine organisms, better protection of public health, and less possibility of having to provide treatment not now planned. Thus, Alternative 1 is the apparent best alternative.

This conclusion has been reflected in action by the State Water Resources Control Board. The board adopted the following statement for inclusion in its April 1975 Addendum to the Water Quality Control Plan, San Francisco Bay Basin:

> "The facilities plan for San Francisco calls for the ultimate disposal of all wastewaters, except some wet weather discharge, from San Francisco into the ocean. This is consistent with the Master Plan developed by the City and County of San Francisco as discussed above. The reasons for the adoption of this concept into the Water Quality Control Plan are as follows:

1. Although adequate protection of beneficial uses can be achieved with either a bay or an ocean discharge, an ocean discharge will provide a higher degree of protection due to its greater dilution potential.

2. The beneficial use of the bay is more intensive than that of the offshore ocean area.

3. The likelihood of increased levels of treatment being required is less for the ocean than for the bay.

4. During certain periods of the year, there is a net southward movement of water into the southern reach of San Francisco Bay, particularly on the west side of the bay. This phenomenon would serve to move wastewater discharged by San Francisco into southern San Francisco Bay and to increase the residence time of that wastewater in the bay. On the other hand, currents in the ocean will generally serve to carry wastes from a properly designed ocean discharge in a southwesterly direction, away from the areas of critical concern.

5. It is the position of the State Department of Fish and Game that an ocean outfall is preferable to bay discharge."

APPENDIX A

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APPENDIX B

Taxonomic Keys

TAXONOMIC KEYS

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APPENDIX C

Chemical Analyses of Pilot Plant Influent and Effluent Samples

Table C-1. Characteristics of Untreated Wastewater and of Effluent of Air Activated Sludge Pilot Plant (Southeast WPCP Service Area)[a,b]

Constituent or characteristic	Standard[c]		Untreated Wastewater			Effluent of air activated sludge process		
	Median	90 percentile	Median	90 percentile[d]	Maximum	Median	90 percentile[d]	Maximum
Major constituents, milligrams per liter, except as noted								
BOD, 5 day	30[e]	45[e]	267	521	570	11.6	32.7	45.0
Settleable solids, ml/l	0.1	0.2	9.0	24.8	32.0	0.1	0.1	0.1
Total suspended solids	30[e]	45[e]	324	772	872	26.0	42.2	56.0
Turbidity, JTU	50	75	118	193	892	10.0	17.4	20.0
Total dissolved solids	-	-	3455	13684	13684	3400	3840	3840
Oil and grease	10	15	84	210	360	2.6	6.4	8.2
Surfactants[f]	-	-	0.8	4.9	5.1	0.2	2.7	2.9
Ammonia - nitrogen[f]	40	60	14.8	20.2	22.8	8.2	13.8	16.0
Alkalinity - $CaCO_3$	-	-	125	161	162	100.0	143	150.0
Minor constituents, micrograms per liter								
Arsenic[g]	10	20	3.5	8.5	9.0	1.9	3.9	4.0
Cadmium[g]	20	30	5.7	9.8	13.0	1.0	1.4	2.0
Total chromium[g]	5	10	1500	4732	6500	92	316	550
Copper[g]	200	300	194	370	560	11.0	25.6	55.0
Cyanide[f]	100	200	40	160	250	10	20	30
Lead[g]	100	200	190	4.5	530	17.0	43.2	480
Mercury[g]	1	2	1.3	15.4	16.8	1.0	22.7	25.0
Nickel[g]	100	200	95	368	610	46.0	114	130
Selenium[g]	-	-	1.0	2.0	2.0	1.0	1.7	1.7
Silver[g]	20	40	28.0	72.4	94.0	1.5	7.2	21.0
Zinc[g]	300	500	700	1600	11000	150	650	1900
Phenol[f]	500	1000	300	500	600	24	50	130
Total chlorinated hydrocarbons[g]	2	4	1.3	2.7	5.0	0.30	0.52	1.86

a. From CH2M Hill, Inc. (1974)

b. From 24 hour composite samples collected from three to seven times a week between September 3 and September 27, 1973.

c. From California State Water Resources Control Board, Water Quality Control Plan - Ocean Waters of California, July 6, 1972, except as noted.

d. Values calculated as not exceeded in 90 percent of the samples

e. 30-day average and 7-day average, respectively. From the Environmental Protection Agency, "Water Programs - Secondary Treatment Information" Federal Register, August 17, 1973.

f. Non-persistent toxicant

g. Persistent toxicant

Table C-2. Characteristics of Physical Chemical Treatment Pilot Plant Effluent (Southeast WPCP Service Area)[a,b]

Constituent or characteristic	Standard[c]		Ferric chloride flocculation, sedimentation			Ferric chloride flocculation, sedimentation, filtration, and activated carbon sorption		
	Median	90 percentile	Median	90 percentile[d]	Maximum	Median	90 percentile[d]	Maximum
Major constituents, milligrams per liter, except as noted								
BOD, 5 day	30[e]	45[e]	73	137	140	29.1	62.4	71.1
Settleable solids, ml/l	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Total suspended solids	30[e]	45[e]	30	61	72	5.4	10.8	12.6
Turbidity, JTU	50	75	20	30	32	2.7	7.2	25.0
Total dissolved solids	-	-	2814	4442	4442	2924	5938	5938
Oil and grease	10	15	2.6	6.6	35.0	2.2	14.8	33.0
Surfactants[f]	-	-	1.6	2.9	2.9	0.10	0.83	0.90
Ammonia - nitrogen[f]	40	60	-	-	-	14.0	18.0	18.4
Alkalinity - $CaCO_3$	-	-	88	113	113	80.0	224	227
Minor constituents, micrograms per liter								
Arsenic[g]	10	20	1.0	2.0	2.0	1.0	2.0	2.0
Cadmium[g]	20	30	1.0	1.5	2.3	1.0	1.0	1.0
Total chromium[g]	5	10	93	188	280	25.0	80.0	95.0
Copper[g]	200	300	15	25	34	7.5	21.2	34.0
Cyanide[f]	100	200	10	60	80	10	40	70
Lead[g]	100	200	8	28	55	5.0	14.0	50.0
Mercury[g]	1	2	1.0	1.9	1.9	1.0	1.6	1.6
Nickel[g]	100	200	62	121	500	45.0	106	182.
Selenium[g]	-	-	1.0	5.0	5.0	1.0	2.7	2.7
Silver[g]	20	40	2.2	5.4	7.0	1.4	2.4	5.0
Zinc[g]	300	500	170	360	3200	110	510	3200
Phenol[f]	500	1000	310	410	530	1	3	4
Total chlorinated hydrocarbons[g]	2	4	0.16	0.46	0.63	0.026	0.106	0.124

a. From CH2M Hill, Inc (1974)

b. From 24 hour composite samples collected from three to seven times a week between September 3 and September 27, 1973.

c. From California State Water Resources Control Board, Water Quality Control Plan - Ocean Waters of California, July 6, 1972, except as noted.

d. Value calculated as not exceeded in 90 percent of the samples

e. 30-day average and 7-day average, respectively. From the Environmental Protection Agency, "Water Programs-Secondary Treatment Information," Federal Register, August 17, 1973.

f. Non-persistent toxicant.

g. Persistent toxicant.

Table C-3. Characteristics of Untreated Wastewater and of Effluent of Air Activated Sludge Pilot Plant (North Point and Southeast WPCP Service Area)[a,b]

Constituent or characteristic	Standard [c]		Untreated Wastewater			Effluent of air activated sludge process		
	Median	90 percentile	Median	90 percentile [d]	Maximum	Median	90 percentile [d]	Maximum
Major constituents, milligrams per liter, except as noted								
BOD, 5 day	30[e]	45[e]	210	314	326	7.0	48.8	104
Settleable solids, ml/l	0.1	0.2	3.2	7.7	11.0	0.1	0.5	0.9
Total suspended solids	30[e]	45[e]	174	339	416	16.0	61.6	178
Turbidity, JTU	50	75	95	117	130	6.7	17.4	29.2
Total dissolved soilds	-	-	2837	4280	4280	2332	2783	2783
Oil and grease	10	15	29.4	65.1	74.4	2.0	6.4	25.2
Surfactants [f]	-	-	1.9	2.9	2.9	0.1	0.1	0.1
Ammonia - nitrogen [f]	40	60	14.4	18.0	18.4	0.60	3.82	5.40
Alkalinity - $CaCO_3$	-	-	145	182	189	67	156	161
Minor constituents, micrograms per liter								
Arsenic [g]	10	20	2.4	6.2	6.4	2.0	3.7	4.0
Cadmium [g]	20	30	3.1	6.9	7.5	1.0	1.4	2.0
Total chromium [g]	5	10	435	1405	1450	94	892	1,300
Copper [g]	200	300	150	266	270	14.0	49.2	56.0
Cyanide [f]	100	200	30	60	70	10	10	10
Lead [g]	100	200	110	572	700	18.0	40.0	50.0
Mercury [g]	1	2	1.2	16.1	22.0	1.0	3.5	4.7
Nickel [g]	100	200	48	476	600	32.0	46	50.0
Selenium [g]	-	-	5	5	5	5.0	5.0	5.0
Silver [g]	20	40	31	107	120	3.0	10.9	14.0
Zinc [g]	300	500	580	1144	1240	290	524	620
Phenol [f]	500	1000	170	220	240	9	15	16
Total chlorinated hydrocarbons [g]	2	4	0.5	1.0	1.1	0.06	0.13	0.18

a. From CH2M Hill, Inc. (1974)

b. From 24 hour composite samples collected from three to seven times a week between October 2 and October 25, 1973

c. From California State Water Resources Control Board, Water Quality Control Plan - Ocean Waters of California, July 6, 1972, except as noted.

d. Values calculated as not exceeded in 90 percent of the samples.

e. 30-day average and 7-day average, respectively. From the Environmental Protection Agency, "Water Programs-Secondary Treatment Information," Federal Register, August 17, 1973

f. Non-persistent toxicant.

g. Persistent toxicant.

Table C-4. Characteristics of Physical Chemical Treatment Pilot Plant Effluent (North Point and Southeast WPCP Service Area)[a,b]

Constituent or characteristic	Standard[c]		Ferric chloride flocculation, sedimentation			Ferric chloride flocculation, sedimentation, filtration, and activated carbon sorption		
	Median	90 percentile	Median	90 percentile[d]	Maximum	Median	90 percentile[d]	Maximum
Major constituents, milligrams per liter, except as noted								
BOD, 5 day	30[e]	45[e]	33.9	64.0	87.4	14.4	40.7	49.5
Settleable solids, ml/l	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Total suspended solids	30[e]	45[e]	19.5	35.0	39.0	5.0	16.5	48.0
Turbidity, JTU	50	75	4.8	8.1	8.6	1.9	4.7	4.8
Total dissolved solids	-	-	2090	3180	3180	2378	2628	2628
Oil and grease	10	15	1.6	5.4	9.4	1.6	5.4	9.4
Surfactants[f]	-	-	1.0	1.7	1.7	0.1	0.1	0.1
Ammonia - nitrogen[f]	40	60	-	-	-	13.6	15.7	16.4
Alkalinity - $CaCO_3$	-	-	117	152	172	103	224	228
Minor constituents, micrograms per liter								
Arsenic[g]	10	20	1.0	3.6	4.6	1.0	2.8	3.0
Cadmium[g]	20	30	1.0	2.1	2.5	1.0	1.0	1.0
Total chromium[g]	5	10	54	128	130	40.0	82.0	100
Copper[g]	200	300	8	18.6	21	40.0	108	120
Cyanide[f]	100	200	20	50	50	40	108	120
Lead[g]	100	200	7.0	20.0	23.0	5.0	16.4	22.0
Mercury[g]	1	2	1.0	1.2	1.4	1.0	1.6	2.0
Nickel[g]	100	200	41	81	90	30	158	230
Selenium[g]	-	-	5	5	5	5	5	5
Silver[g]	20	40	1.0	4.6	5.0	2.0	14.4	16.0
Zinc[g]	300	500	200	532	620	34	168	200
Phenol[f]	500	1000	50	90	90	1	4	4
Total chlorinated hydrocarbons[g]	2	4	40	80	90	0.011	0.084	0.097

a. From CH2M Hill, Inc. (1974)

b. From 24 hour composite samples collected from three to seven times a week between October 2 and October 25, 1973.

c. From California State Water Resources Control Board, Water Quality Control Plan - Ocean Waters of California, July 6, 1972, except as noted.

d. Value calculated as not exceeded in 90 percent of the samples.

e. 30-day average and 7-day average, respectively. From the Environmental Protection Agency, "Water Programs - Secondary Treatment Information," Federal Register, August 17, 1973.

f. Non-persistent toxicant.

g. Persistent toxicant.

APPENDIX D

Statistical Analyses of Bioassay Results

Table D-1. Chi-square Test Comparing the Mean Percent Survival in Undiluted Pilot Plant Effluent from the Southeast WPCP Service Area, 1973

	Test Organism			
Pilot Plant Effluent	Shiner surfperch	English sole	Bay shrimp	Total
Air activated sludge[a]	94.2	98.9	81.0	274.1
Ferric chloride flocculation[b]	87.5	96.1	68.8	252.4
Total	181.7	195.0	149.8	526.5

Chi-square value is 0.39 which is not significant at the 95 percent confidence level.

[a] Refer to Table 6-4
[b] Refer to Table 6-5

Table D-2. Chi-square Tests on Data from Shiner Surfperch Experiments Using Air Activated Sludge Effluent from the Southeast WPCP Service Area, 1973a

Effluent collection date	Result	Effluent concentration, percent 0	10	50	100	Total	Expected value[b]	Chi-square (3df)
Aug. 29	alive	20[c]	20	20	19	79	19.7	3.04 ns
	dead	0[d]	0	0	1	1	0.3	
Aug. 31	alive	10	10	10	10	40	10.0	0.00 ns
	dead	0	0	0	0	0	0.0	
Sept. 4	alive	10	10	10	10	40	10.0	0.00 ns
	dead	0	0	0	0	0	0.0	
Sept. 9	alive	10	10	9	10	39	9.7	3.08 ns
	dead	0	0	1	0	1	0.3	
Sept. 10	alive	10	10	10	10	40	10.0	0.00 ns
	dead	0	0	0	0	0	0.0	
Sept. 11	alive	9	9	8	9	35	8.7	0.69 ns
	dead	1	1	2	1	5	1.3	
Sept. 12	alive	10	10	10	10	40	10.0	0.00 ns
	dead	0	0	0	0	0	0.0	
Sept. 14	alive	9	7	6	8	30	7.5	2.67 ns
	dead	1	3	4	2	10	2.5	
Sept. 15	alive	8	7	6	7	28	7.0	0.95 ns
	dead	2	3	4	3	12	3.0	
Sept. 16	alive	10	10	9	9	38	9.5	2.11 ns
	dead	0	0	1	1	2	0.5	
Sept. 24	alive	10	10	10	10	40	10.0	0.00 ns
	dead	0	0	0	0	0	0.0	
Sept. 25	alive	10	10	10	10	40	10.0	0.00 ns
	dead	0	0	0	0	0	0.0	
Sept. 26	alive	10	10	10	10	40	10.0	0.00 ns
	dead	0	0	0	0	0	0.0	
Total	(39 df)							12.54 ns

[a]Refer to Table 6-4 in text.

[b]Expected value is the same for each effluent concentration tested.

[c]Number of fishes surviving after 96 hours exposure.

[d]Number of dead fishes after 96 hours exposure.

ns - Not significant at the 95 percent confidence level.

df - Degrees of freedom.

Table D-3. Chi-square Tests on Data from English Sole Experiments Using Air Activated Sludge Effluent from the Southeast WPCP Service Area, 1973[a]

Effluent collection date	Effluent concentration, percent 0	10	50	100	Total	Expected value[b]	Chi-square (3df)
Aug. 29	20[c]	20	20	20	80	20.0	0.00 ns
	0[d]	0	0	0	0	0.0	
Aug. 31	10	10	10	10	40	10.0	0.00 ns
	0	0	0	0	0	0.0	
Sept. 4	10	10	9	10	39	9.7	3.08 ns
	0	0	1	0	1	0.3	
Sept. 5	10	10	10	10	40	10.0	0.00 ns
	0	0	0	0	0	0.0	
Sept. 6	20	19	20	19	78	19.5	2.05 ns
	0	1	0	1	2	0.5	
Sept. 7	10	10	10	10	40	10.0	0.00 ns
	0	0	0	0	0	0.0	
Sept. 9	9	10	8	10	37	9.3	3.96 ns
	1	0	2	0	3	0.7	
Sept. 10	10	10	10	10	40	10.0	0.00 ns
	0	0	0	0	0	0.0	
Sept. 12	9	9	10	10	38	9.5	2.11 ns
	1	1	0	0	2	0.5	
Sept. 14	8	10	10	9	37	9.3	3.96 ns
	2	0	0	1	3	0.7	
Sept. 15	10	10	10	10	40	10.0	0.00 ns
	0	0	0	0	0	0.0	
Sept. 17	10	10	9	10	39	9.7	3.08 ns
	0	0	1	0	1	0.3	
Sept. 25	9	9	10	10	38	9.5	2.11 ns
	1	1	0	0	2	0.5	
Sept. 26	10	10	10	10	40	10.0	0.00 ns
	0	0	0	0	0	0.0	
Total (42 df)							20.35 ns

[a]Refer to Table 6-4 in text.

[b]Expected value is the same for each effluent concentration tested.

[c]Number of fishes surviving after 96 hours exposure.

[d]Number of dead fishes after 96 hours exposure.

ns - Not significant at the 95 percent confidence level.
df - Degrees of freedom.

Table D-4. Chi-square Tests on Data from Bay Shrimp Experiments Using Air Activated Sludge Effluent from the Southeast WPCP Service Area, 1973[a]

Effluent collection date	Effluent concentration, percent 0	10	50	100	Total	Expected value[b]	Chi-square (3df)
Aug. 29	16[c]	18	18	18	70	17.5	1.37 ns
	4[d]	2	2	2	10	2.5	
Sept. 5	17	11	14	14	56	14.0	4.29 ns
	3	9	6	6	24	6.0	
Sept. 7	17	16	13	16	62	15.5	2.58 ns
	3	4	7	4	18	4.5	
Sept. 11	16	14	16	17	63	15.7	1.42 ns
	4	6	4	3	17	4.3	
Sept. 16	9	9	9	8	35	8.7	2.07 ns
	1	1	1	2	5	1.3	
Total (15 df)							

[a]Refer to Table 6-4 in text.

[b]Expected value is the same for each effluent concentration tested.

[c]Number of shrimp surviving after 96 hours exposure.

[d]Number of dead shrimp after 96 hours exposure.

ns - Not significant at the 95 percent confidence level.

df - Degrees of freedom.

Table D-5. Chi-square Tests on Data from Shiner Surfperch Experiments Using Ferric Chloride Effluent from the Southeast WPCP Service Area, 1973[a]

Effluent collection date	Effluent concentration, percent 0	10	50	100	Total	Expected value[b]	Chi-square value (3df)
Aug. 30	20	20	20	20	80	20.0	0.00 ns
	0[d]	0	0	0	0	0.0	
Aug. 31	10	10	10	10	40	10.0	0.00 ns
	0	0	0	0	0	0.0	
Sept. 4	10	10	10	10	40	10.0	0.00 ns
	0	0	0	0	0	0.0	
Sept. 9	10	9	10	9	38	9.5	2.11 ns
	0	1	0	1	2	0.5	
Sept. 10	10	10	10	10	40	10.0	0.00 ns
	0	0	0	0	0	0.0	
Sept. 11	10	9	9	8	36	9.0	2.22 ns
	0	1	1	2	4	1.0	
Sept. 12	10	10	10	2	32	8.0	30.00 ***
	0	0	0	8	8	2.0	
Sept. 15	8	10	7	6	31	7.7	5.02 ns
	2	0	3	4	9	2.3	
Sept. 16	8	7	7	10	32	8.0	3.75 ns
	2	3	3	0	8	2.0	
Sept. 24	10	10	–[e]	10	30	10.0	0.00 ns
	0	0	–	0	0	0.0	
Sept. 25	10	10	10	10	40	10.0	0.00 ns
	0	0	0	0	0	0.0	
Sept. 26	10	10	10	10	40	10.0	0.00 ns
	0	0	0	0	0	0.0	
Total (36 df)							43.10 ns

[a]Refer to Table 6-5 in text.

[b]Expected value is the same for each effluent concentration tested.

[c]Number of fishes surviving after 96 hours exposure.

[d]Number of dead fishes after 96 hours exposure.

[e]Mortality caused by a malfunction in the aeration system.

***Significant at the 99.9 percent confidence level.

ns - Not significant at the 95 percent confidence level.

df - Degree of freedom

Table D-6. Chi-square Tests on Data from English Sole Experiments Using Ferric Chloride Effluent from the Southeast WPCP Service Area, 1973[a]

Effluent collection date	Effluent concentration, percent 0	10	50	100	Total	Expected value[b]	Chi-square value (3df)
Aug. 30	10[c] 0[d]	10 0	10 0	10 0	40 0	10.0 0.0	0.00 ns
Aug. 31	10 0	10 0	10 0	10 0	40 0	10.0 0.0	0.00 ns
Sept. 4	10 0	10 0	10 0	10 0	40 0	10.0 0.0	0.00 ns
Sept. 5	10 0	10 0	10 0	10 0	40 0	10.0 0.0	0.00 ns
Sept. 6	19 1	19 1	20 0	19 1	77 3	19.3 0.7	1.04 ns
Sept. 7	10 0	10 0	10 0	7 3	37 3	9.3 0.7	9.73 ns
Sept. 9	10 0	8 2	9 1	9 1	36 4	9.0 1.0	2.22 ns
Sept. 10	10 0	10 0	10 0	10 0	40 0	10.0 0.0	0.00 ns
Sept. 12	10 0	9 1	10 0	9 1	38 2	9.5 0.5	2.11 ns
Sept. 14	9 1	10 0	10 0	10 0	39 1	9.7 0.3	3.08 ns
Sept. 15	10 0	9 1	10 0	10 0	39 1	9.7 0.3	3.08 ns
Sept. 17	10 0	10 0	10 0	10 0	40 0	10.0 0.0	0.00 ns
Sept. 25	8 2	10 0	9 1	10 0	37 3	9.3 0.7	3.96 ns
Sept. 26	10 0	10 0	10 0	10 0	40 0	10.0 0.0	0.00 ns
Total (42 df)							25.22 ns

[a]Refer to Table 6-5 in text.

[b]Expected value is the same for each effluent concentration tested.

[c]Number of fishes surviving after 96 hours exposure.

[d]Number of dead fishes after 96 hours exposure.

ns - Not significant at the 95 percent confidence limit.

df - Degrees of freedom.

Table D-7. Chi-square Tests on Data from Bay Shrimp Experiments Using Ferric Chloride Effluent from the Southeast WPCP Service Area, 1973[a]

Effluent collection date	Effluent concentration, percent 0	10	50	100	Total	Expected value[b]	Chi-square value (3df)
Aug. 30	19[c]	18	17	14	68	17	5.49 ns
	1[d]	2	3	6	12	3	
Sept. 11	16	15	16	13	60	15	1.60 ns
	4	5	4	7	20	5	
Sept. 16	9	10	8	8	35	8.7	2.51 ns
	1	0	2	2	5	1.3	
Sept. 24	9	9	5	6	29	7.3	6.39 ns
	1	1	5	4	11	2.7	
Total (12 df)							15.99 ns

[a]Refer to Table 6-5 in text.

[b]Expected value is the same for each effluent concentration tested.

[c]Number of shrimp surviving after 96 hours exposure.

[d]Number of dead shrimp after 96 hours exposure.

ns - Not significant at the 95 percent confidence level.

df - Degrees of freedom.

Table D-8. Chi-square Tests on Data from Experiments Using Air Activated Sludge Effluent from the North Point - Southeast WPCP Service Areas, 1973[a]

A. Shiner surfperch

(All test organisms survived in these tests. The chi-square value is zero.)

B. English sole

Effluent collection date	Effluent concentration, percent 0	10	50	100	Total	Expected value[b]	Chi-square value (3df)
Oct. 2	10[c]	10	10	9	39	9.7	3.08 ns
	0[d]	0	0	1	1	0.3	
Oct. 3	10	10	8	9	37	9.3	3.96 ns
	0	0	2	1	3	0.7	
Oct. 9	9	10	10	10	39	9.7	3.08 ns
	1	0	0	0	1	0.3	
Oct. 10	10	10	10	10	40	10.0	0.00 ns
	0	0	0	0	0	0.0	
Oct. 13	10	10	9	10	39	9.7	3.08 ns
	0	0	1	0	1	0.3	
Oct. 15	10	10	10	10	40	10.0	0.00
	0	0	0	0	0	0.0	
Oct. 17	9	10	10	9	38	9.5	2.11 ns
	1	0	0	1	2	0.5	
Total (21 df)							15.31 ns
C. Bay shrimp							
Oct. 4	8[c]	9	9	9	35	8.7	0.69 ns
	2[d]	1	1	1	5	1.3	
Oct. 7	8	10	10	10	38	9.5	6.32 ns
	2	0	0	0	2	0.5	
Oct. 12	9	9	9	7	34	8.5	2.35 ns
	1	1	1	3	6	1.5	
Total (9 df)							9.36 ns

[a]Refer to Table 6-7 in text.

[b]Expected values is the same for all effluent concentrations tested.

[c]Number of organisms surviving after 96 hours exposure.

[d]Number of dead organisms after 96 hours exposure.

ns - Not significant at the 95 percent confidence level.

df - Degree of freedom.

Table D-9. Chi-square Test Comparing the Mean Percent Survival in Undiluted Pilot Plant Effluent from the North Point - Southeast WPCP Service Areas, 1973

	Test Organism			
Pilot Plant Effluent	Shiner surfperch	English sole	Bay shrimp	Total
Air activated sludge[a]	100	95.7	83.3	279.0
Ferric chloride flocculation[b]	100	97.1	87.5	284.6
Total	200	192.8	170.8	563.6

Chi-square value is 0.06 which is not significant at the 95 percent confidence level.

[a] Refer to Table 6-7
[b] Refer to Table 6-8

Table D-10. Chi-square Tests on Data from Experiments Using Ferric Chloride Effluent from the North Point - Southeast WPCP Service Areas, 1973[a]

A. Shiner surfperch

(All test organisms survived in these tests. The chi-square value is zero.)

B. English sole

Effluent collection date	Effluent concentration, percent 0	10	50	100	Total	Expected value[b]	Chi-square value (3df)
(All test organisms survived in effluent samples collected October 2, 9, 10, 15, and 17. The chi-square values for these tests are zero.)							
Oct. 3	9[c]	10	10	9	38	9.5	2.11 ns
	1[d]	0	0	1	2	0.5	
Oct. 13	10	10	10	9	39	9.7	3.08 ns
	0	0	0	1	1	0.3	
Total (21 df)							5.19 ns
C. Bay shrimp							
Oct. 4	10[c]	8	8	9	35	8.7	2.51 ns
	0[d]	2	2	1	5	1.3	
Oct. 5	9	7	8	9	33	8.3	1.90 ns
	1	3	2	1	7	1.7	
Oct. 7	8	9	7	10	34	8.5	3.92 ns
	2	1	3	0	6	1.5	
Oct. 8	9	8	10	7	34	8.5	3.92 ns
	1	2	0	3	6	1.5	
Total (12 df)							12.25 ns

[a]Refer to Table 6-8 in text.

[b]Expected value is the same for all effluent concentrations tested.

[c]Number of organisms surviving after 96 hours exposure.

[d]Number of dead organisms after 96 hours exposure.

ns - Not significant at the 95 percent confidence level.

df - Degrees of freedom

Table D-11. Chi-square Tests on Data from Experiments Using Ferric Chloride Effluent Without Activated Carbon Sorption from the North Point - Southeast WPCP Service Areas, 1973[a]

Effluent collection date	Effluent concentration, percent				Expected value			Chi-square value (2 df)
	0	50	100	Total	0	50	100	
A. Shiner surfperch								
Oct. 18	10[b]	10	29	49	9.8	9.8	29.4	0.68 ns
	0[c]	0	1	1	0.2	0.2	0.6	
Oct. 19	10	10	29	49	9.8	9.8	29.4	0.68 ns
	0	0	1	1	0.2	0.2	0.6	
Oct. 22	10	10	27	47	9.4	9.4	28.2	2.13 ns
	0	0	3	3	0.6	0.6	1.8	
Oct. 24	10	10	26	46	9.2	9.2	27.6	2.90 ns
	0	0	4	4	0.8	0.8	2.4	
Total (8 df)								6.39 ns
B. English sole								
(All test organisms survived in effluent samples collected October 18, 19, and 24. The chi-square values for these tests are zero.)								
Oct. 22	10[b]	10	29	49	9.8	9.8	29.4	0.68 ns
	0[c]	0	1	1	0.2	0.2	0.6	
Total (8 df)								0.68 ns
C. Bay Shrimp								
Oct. 22	8[b]	8	23	39	7.8	7.8	23.4	0.08 ns
	2[c]	2	7	11	2.2	2.2	6.6	
Oct. 24	9	7	21	37	7.4	7.4	22.2	1.59 ns
	1	3	9	3	2.6	2.6	7.8	
Total (4 df)								1.67 ns

[a]Refer to Table 6-9 in text.

[b]Number of organisms surviving after 96 hours exposure.

[c]Number of dead organisms after 96 hours exposure.

ns - Not significant at the 95 percent confidence level.

df - Degrees of freedom.

Table D-12. Analysis of Variance Tables for Dungeness Crab Toxicity Experiments, 1974

A. Percentage of zoeae obtained from Steinhart and synthetic seawater (data from Table 6-13 in text)

Source of variation	df	SS	MS	F_s
Subgroups	5	81.40	16.28	
seawater	1	11.68		0.595 ns
experiment	2	60.52	30.26	1.542 ns
interaction	2	9.19	4.60	0.234 ns
Experimental error	12	235.42	19.62	

B. Percentage of zoeae obtained from Steinhart and synthetic seawater with ten percent air activated sludge or ferric chloride effluent added (data from Table 6-14 in text).

Source of variation	df	SS	MS	F_s
Subgroups	5	37.68	7.54	
seawater	2	26.88	13.44	0.618 ns
treatment	1	10.73	10.73	0.494 ns
interaction	2	0.07	0.04	0.002 ns
Experimental error	12	260.90	21.74	

C. Percentage of zoeae obtained from activated sludge effluent (data from Table 6-15 in text).

Source of variation	df	SS	MS	F_s
Subgroups	14	657.12	46.51	
concentrations	4	117.78	29.45	0.99 ns
experiment	2	178.66	89.33	3.00 ns
interaction	8	354.67	44.33	1.49 ns
Experimental error	30	891.96	29.73	

Table D-12. Analysis of Variance Tables for Dungeness Crab Toxicity Experiments, 1974 (continued)

D. Percentage of zoeae obtained from ferric chloride effluent (data from Table 6-15 in text).

Source of variation	df	SS	MS	F_s
Subgroups	14	8614.6		
concentration	4	5014.7	1253.7	29.92***
experiment	2	1715.3	857.6	20.47***
interaction	8	1884.7	235.6	5.62**
Experimental error	30	1257.0	41.9	

E. Survival of zoeae in activated sludge effluent (data from Table 6-16 in text).

Source of variation	df	SS	MS	F_s
Subgroups	35	3100	88.56	
concentration	3	163.3	54.43	0.847 ns
experiment	8	1431.9	178.99	2.786*
interaction	24	1504.5	62.69	0.976 ns
Experimental error	72	4625.0	64.24	

F. Survival of zoeae in ferric chloride effluent (data from Table 6-16 in text).

Source of variation	df	SS	MS	F_s
Subgroups	35	99897	2854	
concentration	3	67780	22593	174.0***
experiment	8	9440	1180	9.087***
interaction	24	22676	944.8	7.275***
Experimental error	72	9351	129.9	

ns Not significant at the 95 percent confidence level

* Significant at the 95 percent confidence level

** Significant at the 99 percent confidence level

*** Significant at the 99.9 percent confidence level

Table D-13. Chi-square Tests on Data from Crab Zoeae Experiments Using Effluents from the Southeast WPCP Service Area, 1974[a]

Experiment	Effluent concentration, percent 0	10	20	50	Total	Expected value 0	10	20	50	Chi-square value (3 df)
A. Air activated sludge effluent										
P-1	29[b]	28	28	27	112	27.3	28.2	28.2	28.2	2.80 ns
	0[c]	2	2	3	7	1.7	1.8	1.8	1.8	
R-1	28	25	23	22	98	24.1	24.1	24.1	25.7	6.35 ns
	2	5	7	10	24	5.9	5.9	5.9	6.3	
Total (6 df)										9.15 ns
B. Ferric chloride flocculation and sedimentation effluent										
P-1	30[b]	24	11	0	65	16.3	16.3	16.3	16.3	72.60**
	0[c]	6	19	30	55	13.7	13.7	13.7	13.7	
R-1	28	25	14	0	67	16.5	16.5	17.6	16.5	65.82**
	2	5	18	30	55	13.5	13.5	12.4	13.5	
Total (6 df)										138.42**

[a] Refer to Table 6-18 in text

[b] Number of zoeae surviving after 96 hours exposure

[c] Number of dead zoeae after 96 hours exposure

ns Not significant at the 95 percent confidence level

** Significant at the 99 percent confidence level

df Degrees of freedom

Table D-14. Chi-square Tests on Data from Chronic Crab Zoeae Experiments Using Effluent from the Southeast WPCP Service Area, 1974[a]

Experiment	Effluent concentration, percent 0	1	5	10	Total	Expected value 0	1	5	10	Chi-square value (3 df)
A. Air activated sludge effluent										
E-C	23[b]	23	22	21	89	22.1	22.1	22.8	22.1	0.67 ns
	6[c]	6	8	8	28	6.9	6.9	7.2	6.9	
R-C	24	27	26	25	102	25.5	25.5	25.5	25.5	1.31 ns
	6	3	4	5	18	4.5	4.5	4.5	4.5	
Total (6 df)										1.98 ns
B. Ferric chloride effluent										
E-C	23[b]	25	6	0	54	13.4	13.4	13.4	13.8	64.83**
	6[c]	4	23	30	63	15.6	15.6	15.6	16.2	
R-C	24	24	20	13	81	20.9	19.6	19.6	20.9	14.86**
	6	4	8	17	35	9.1	8.4	8.4	9.1	
Total (6 df)										79.69**

[a]Refer to Table 6-20 in text

[b]Number of zoeae surviving after 96 hours exposure

[c]Number of dead zoeae after 96 hours exposure

ns Not significant at the 95 percent confidence level

** Significant at the 99 percent confidence level

df Degrees of freedom

APPENDIX E

Dispersion of Effluent Discharged to San Francisco Bay

DISPERSION OF EFFLUENT DISCHARGED
TO SAN FRANCISCO BAY

During the period of the 1973-74 investigation, the State of California was engaged in a concurrent development of the "Water Quality Control Plan, San Francisco Bay Basin". That study included the development of improved mathematical models of the hydrodynamics and the water quality of the entire bay system. The water quality model was used to predict receiving water characteristics under various conditions of Delta outflow and of waste load inputs to the bay. A subtask of the present investigation was to undertake special runs of the model, if necessary, to show the effect of a major discharge of wastewater effluent to the bay near the Southeast WPCP. Of particular concern was the possible effect of nitrogen in the San Francisco effluent on the nitrogen content of the waters of the South Bay. A need for removal of nitrogen from discharges directly into the South Bay must be anticipated in the future.

The mathematical water quality control model is the latest of a series of models which in turn are based on the relatively abundant basic data on water movements and water quality made available to studies of the bay during the past 15 to 20 years.

Both the hydrodynamic and the water quality model represent the bay by means of a series of nodes and intermediate links or pathways. The hydrodynamic model, using the known pattern of changing tidal elevations and Delta outflow, is able to compute velocities and flows between each link throughout a tidal cycle. From these, it determines the net advective flow and effective dispersion properties of each part of the bay and of the bay system.

The water quality model utilizes the output of the hydrodynamic model and predetermined inputs of waste loads. It calculates either steady-state values or time-history (build-up) values of water quality characteristics. The model was calibrated against a recorded conservative characteristic such as chloride concentration over a span of several months.

Model Input

For estimating the effect of a major San Francisco discharge, the following assumptions and inputs were used:

1. Source - North Point and Southeast tributary zones.

2. Volume - Average dry weather volume of 94 mgd, for year 2000.

3. Discharge point - One-half to Node 3, situated south of Yerba Buena Island, one-half to Node 17 situated near Hunter's Point. The present Southeast outfall lies approximately halfway between these nodes.

4. Delta outflow - 1800 cfs.

The computer analysis was made for four treatment and disposal alternatives, as follows:

1. North Point - Southeast (NP-SE) discharge to ocean. All discharges to the far South Bay to receive secondary treatment plus nitrification. No discharge south of Dumbarton Bridge.

2. NP-SE to bay after secondary treatment. Other discharges as in case 1.

3. NP-SE to ocean. East Bay Municipal Utility District to provide nitrification. Other discharges to provide nitrification-denitrification (i.e., nitrogen removal).

4. NP-SE to bay after nitrification. All other discharges as in case 3.

Results of Model Runs

Output for the steady-state concentration of total nitrogen, ultimate oxygen demand (UOD), both in milligrams per liter and toxicity, expressed in toxicity units, are shown in Table E-1. It will be noted that the differences between ocean disposal and bay disposal are minor in absolute value and would generally fall within normal sampling and analytical variations.

On a relative basis, the San Francisco discharge to the bay would contribute 4 to 5 percent of the total nitrogen present in the nitrogen-sensitive southern reach of the bay after local dischargers provide for its removal (case 4). Although this nitrogen along with that from the East Bay may be considered a significant fraction, we do not believe it is sufficient to warrant a future requirement for nitrogen removal for the San Francisco discharge.

Both toxicity (here assumed to be 0.6 units in the San Francisco discharge) and nitrogen are assumed to be conservative; that is, not changed during their period of residence in the bay. They thus act in the model as tracers and indicate that effluent from the southeast site which is dispersed southward achieves a steady state (dry weather) dilution of about 250 to 1 in the main body of the South Bay. In this connection, however, it should be noted that the model does not take into account density stratification which occurs to a degree even in the summer in the northern portion of the South Bay and enhances seaward advection.

Table E-1. Results of Mathematical Water Quality Model Analysis of Effect of Discharge at Southeast Site

Parameter	Model node and location				
	3	17	20	32	44
	S. of Yerba Buena	Hunters Point	Brisbane	Mid South Bay	N. of Dumbarton Bridge
Total nitrogen, mg/l					
1. NP-SE to ocean[a]	0.56	0.68	0.73	1.11	2.76
2. NP-SE to bay, secondary tr.[a]	0.60	0.75	0.79	1.17	2.82
3. NP-SE to ocean[b]	0.50	0.54	0.57	0.64	0.86
4. NP-SE to bay, nitrification[b]	0.52	0.59	0.62	0.69	0.90
Toxicity, in toxicity units					
1. NP-SE to ocean[a]	0.015	0.017	0.018	0.026	0.057
2. NP-SE to bay, secondary tr.[a]	0.015	0.019	0.020	0.027	0.058
3. NP-SE to ocean[b]	0.014	0.016	0.016	0.022	0.045
4. NP-SE to bay, nitrification[b]	0.014	0.017	0.018	0.024	0.047
Ultimate oxygen demand mg/l					
1. NP-SE to ocean[a]	0.23	0.24	0.19	0.17	1.00
2. NP-SE to bay, secondary tr.[a]	0.31	0.39	0.29	0.21	0.98
3. NP-SE to ocean[b]	0.15	0.12	0.11	0.10	0.71
4. NP-SE to bay, nitrification[b]	0.16	0.16	0.13	0.11	0.70

[a] South bay dischargers to provide nitrification, no discharge south of Dumbarton Bridge.

[b] South bay dischargers to provide for nitrogen removal; East Bay and San Francisco (if to bay) to provide for nitrification.

APPENDIX F

An Analysis of Possible Seasonal Variations in the Catch Composition in the Vicinity of the Proposed Outfall Site in the Gulf of the Farallones, 1973-1974

AN ANALYSIS OF POSSIBLE SEASONAL VARIATIONS IN THE CATCH COMPOSITION OF FISHES COLLECTED IN THE VICINITY OF A PROPOSED OUTFALL SITE IN THE GULF OF THE FARALLONES, 1973-1974

A supplemental analysis has been made of data on fishes obtained from trawl surveys made in 1973 and 1974 and described in Chapter 4. A review has also been made of the literature on selected species of fishes. The analysis and literature review concern possible seasonal variations in the catch composition of fishes collected in the vicinity of the proposed treated wastewater outfall in the Gulf of the Farallones.

As discussed in Chapter 4, the trawl net used was a 42-foot crab sampling net. Trawling surveys were made on July 17 and 18, 1973; October 16, 1973; and April 5, 1974. These sampling dates were chosen to coincide with the major oceanographic periods so that possible seasonal changes in the benthic fauna could be assessed. The surveys made in July and October 1973 coincided with the Upwelling and Oceanic Periods, respectively, and the April 1974 survey was made during the rainy season. Although the latter is not an oceanographic period, it was felt that the high freshwater outflow from the San Francisco Bay-Delta system, with the possible consequent changes in salinity, could have a significant effect on the faunal composition of the study area. The sampling program consisted of the collection of samples at twelve stations for each of the three surveys. The station locations were selected to correspond to depth contours and were also distributed with respect to the sampling grid.

Trawling time was recorded from the time the collecting gear reached bottom and began fishing to the time the winch was started to haul in the net. On the July survey, each trawl was for ten minutes. During this survey, the entire catch in the first six trawls was saved, but because of the enormity of the combined catches, subsamples were taken from the remaining six trawl catches. The trawl time was shortened to five minutes in the subsequent October 1973 and April 1974 surveys. Analyzing the entire catch of a five-minute trawl was judged superior to the subsampling of a ten-minute trawl, since it would avoid the errors inherent in subsampling. Both a five-minute and ten-minute trawl were made at Station 41.5-3 during the October 1973 and April 1974 surveys. A comparison of the findings is presented in Appendix I, contained in A Predesign Report on Marine Waste Disposal, Volume V.

Forty-eight species of fishes representing 27 families were collected during this study (Table F-1). Twenty-seven species of fishes were collected on all three of the surveys. The highest number of species was found in July (41), the second highest in October (36), and the lowest in April (33). The differences in the results between these three surveys not only reflects the difference in the total number of species collected in five-minute and ten-minute trawls, it also reflects the capture of species less commonly found in the study area (i.e. indicated by their infrequent capture) and seasonal variation in abundance and composition of the fish fauna. An example of seasonal variation in the composition of the fish fauna was demonstrated in the collection of Pacific hake and Dover sole in only the July survey. Both these species migrate inshore during the spring and summer and return offshore in the fall and winter to spawn (Alverson, 1960).

Table F-1. Number and Weight of Fishes by Species, Gulf of the Farallones

Species	July 1973[a]		October 1973		April 1974		Total	
	Number	Weight, kg	Number	Weight, kg	Number	Weight, kg	Number	Weight, kg
Pacific tomcod	17,772	70.9	5,763	56.0	1,873	20.3	25,408	147.2
English sole	16,261	1,352.1	5,227	224.2	3,650	512.3	25,138	2,088.7
Speckled sanddab	10,510	107.8	3,717	34.7	2,065	26.2	16,283	168.7
Pacific sanddab	5,306	540.7	311	23.3	429	30.7	6,046	594.7
Whitebait smelt	-	-	38	0.2	4,981	11.2	5,019	11.5
White croaker	685	95.5	2,527	70.5	1,673	93.6	4,885	259.6
Night smelt	1,290	4.5	1,970	8.0	-	-	3,260	12.4
Shiner surfperch	24	0.7	1,916	21.9	849	11.1	2,789	33.6
Spotfin surfperch	484	6.2	1,760	7.7	344	3.4	2,688	17.3
Northern anchovy	396	5.4	35	6.0	1,036	8.6	2,067	14.6
Plainfin midshipman	160	11.1	1,277	2.4	78	7.6	1,515	21.2
Sand sole	437	83.9	295	51.1	340	53.6	1,072	188.7
Curlfin turbot	765	100.8	146	27.7	128	21.2	1,039	149.7
Staghorn sculpin	417	44.5	391	27.1	178	14.0	986	85.7
Petrale sole	480	80.8	1	0.3	-	-	484	81.1
Big skate	190	120.8	50	31.2	107	146.4	347	298.5
White surfperch	86	11.1	207	14.4	4	0.4	297	25.9
Spiny dogfish	195	97.8	2	0.9	3	3.3	200	101.9
Pacific herring	170	1.0	21	0.1	6	0.3	197	1.4
Dover sole	129	29.4	-	-	-	-	129	29.4
Rex sole	114	18.7	-	-	1	0.2	115	18.9
Starry flounder	58	41.8	28	24.0	11	3.6	97	69.4
Lingcod	55	1.3	1	T	7	T	63	1.3
Brown rockfish	49	24.3	-	-	8	5.3	57	29.6
Pacific butterfish	39	0.6	2	T	13	0.2	54	0.8
California tonguefish	1	T	48	0.7	4	0.1	53	0.8
Longfin smelt	-	-	51	0.2	-	-	51	0.2
Hornyhead turbot	26	1.4	16	1.5	6	1.4	48	4.3
Pile surfperch	34	6.6	6	0.4	2	0.6	42	7.6
Pacific hake	39	47.9	-	-	-	-	39	47.9
Brown smoothhound	2	1.6	2	0.9	31	43.3	35	45.9
Bat ray	-	-	1	9.1	18	54.3	19	63.4
Spotted cusk-eel	7	0.2	5	0.1	1	T	14	0.2
Pricklebreast poacher	3	T	4	T	5	T	12	0.1
Rock sole	2	0.8	1	0.2	7	1.0	10	2.0
Warty poacher	2	T	7	T	-	-	9	T
Leopard shark	-	-	-	-	7	22.0	7	22.0
Showy snailfish	-	-	5	0.1	1	T	6	0.1
California halibut	2	14.1	1	2.1	2	2.1	5	18.3
Longspine combfish	4	0.2	-	-	-	-	4	0.2
California skate	3	5.0	-	-	-	-	3	5.0
Pink surfperch	3	0.1	-	-	-	-	3	0.1
Rubberlip surfperch	-	-	2	0.2	-	-	2	0.2
Pygmy poacher	2	T	-	-	-	-	2	T
Pacific sandlance	2	T	-	-	-	-	2	T
Pacific electric ray	1	2.7	-	-	-	-	1	2.7
Green sturgeon	1	2.4	-	-	-	-	1	2.4
Bay pipefish	-	-	1	T	-	-	1	T
Total	56,507	2,934.9	25,835	642.0	18,659	1,098.6	100,104	4675.5

[a]Calculated number and weight of fishes from aliquots

T (trace) represents weights less than 0.1 kg

A seasonal comparison of the density of population for each fish species cannot readily be made because of the possible differences in the catch composition of five-minute and ten-minute trawls. The percent composition of the five species of benthic fishes more commonly collected during the surveys (Pacific tomcod, Pacific sanddab, white croaker, speckled sanddab, and English sole) varied among the surveys as indicated in Table F-2. The fluctuation is partly caused by the presence or absence of a large number of pelagic fishes (e.g., species of smelt, northern anchovy, and Pacific herring) collected in each survey. However, if the percent composition by number of each species is adjusted to omit the presence of pelagic fishes in the catch, only three of the five more commonly collected species show a fluctuation in abundance. With the adjusted numbers, the Pacific tomcod comprised 32.0 percent of the catch by number in the July survey, 22.3 percent in October, and 10.0 percent in April. This apparent decrease in relative abundance can in part be explained by an examination of the length frequency distribution for this species (Fig. F-1). In July, 96 percent of the catch of this species was composed of individuals less than 90 mm long, which indicates an influx of fish-of-the-year into the study area. The increase in the median size for these fishes in the three surveys reflects their seasonal growth. As with many other species of marine fishes, the Pacific tomcod may concentrate in inshore areas during their first year and gradually disperse into offshore waters.

Again with adjusted values, the Pacific sanddab also showed a decrease in percent composition from a high of 9.4 percent in July to a low of 1.2 percent in October and 2.3 percent in April. This decrease in the percent composition in the three survyes reflects the relative lack of Pacific sanddabs larger than 150 mm in the October and April catches (Fig. F-2). This species has been reported at depths from 10 to 100 fathoms, but it is most plentiful at from 20 to 50 fathoms. Therefore, their collection in the study area is at the upper bathymetric range for this species. In addition, most Pacific sanddabs spawn from July to October and may move offshore to spawn, as do other flatfish species. This would explain the absence of the larger specimens in the later surveys, since females become mature as early as 150 mm SL (Standard length) and are all mature at 190 mm SL (Arora, 1951). No data is given on the length at maturity for males, but it is probably in the same size range.

White croakers increased in the adjusted percent composition by number from a low of 1.2 percent in July to a high of 9.8 percent in October and 9.0 percent in April. This increase is primarily caused by the collection of large numbers of juveniles and fish-of-the-year less than 130 mm SL in the October, 1973 and April, 1974 surveys (Fig. F-3). Most white croakers spawn once in the early spring months, but some of them spawn more than once each season (Fitch, 1965).

The adjusted percent composition for speckled sanddabs remained fairly stable between 16.0 and 19.3 percent. The speckled sanddab is a common inshore species which rarely exceeds 160 mm. The respective median size were 82, 82, and 89 mm for July, October, and April (Fig. F-4).

The percent composition of English sole did not change appreciably. English sole made up between 19.7 and 28.9 percent of the catch. However, the size composition did change (Fig. F-5). To analyze these differences, the lengths were divided into year classes based on the results of an age and growth study of English sole collected in Monterey Bay (Smith and Nitsos, 1969). The total length of English sole at ages one, two, three, and four were found to be 140, 200, 250, and 290 mm. Using a conversion factor to derive standard length from total length by dividing the total length by 1.178, the respective standard lengths are 120, 170, 210, and 250 mm (Tom Jow, Biologist, California Department of Fish and Game, personal communication,

Table F-2. Percent Composition by Number and Weight of Fishes by Species, Gulf of the Farallones

Species	July 1973		October 1973		April 1974		Mean	
	Number percent	Weight percent	Number percent	Weight percent	Number percent	Weight percent	Number percent	Weight percent
Pacific tomcod	32.0	2.4	22.3	8.7	10.1	1.8	25.2	3.1
English sole	28.9	46.0	20.2	34.9	19.7	46.1	25.0	44.7
Speckled sanddab	18.7	3.7	14.4	5.4	11.1	2.4	16.2	3.6
Pacific sanddab	9.4	18.4	1.2	3.6	2.3	2.8	6.0	12.7
Whitebait smelt	-	-	0.2	<0.1	26.9	1.0	5.0	0.2
White croaker	1.2	3.2	9.8	11.0	9.0	8.5	4.8	5.5
Night smelt	2.3	0.1	7.6	1.2	-	-	3.2	0.3
Shiner surfperch	0.1	<0.1	7.4	3.4	4.6	1.0	2.8	0.7
Spotfin surfperch	0.3	0.2	6.8	1.2	1.9	0.3	2.2	0.4
Northern anchovy	0.7	0.2	0.1	0.1	9.9	0.8	2.2	0.3
Plainfin midshipman	0.3	0.4	4.9	0.4	0.4	0.7	1.5	0.4
Sand sole	0.8	2.8	1.1	8.0	1.8	4.9	1.1	4.0
Curlfin turbot	1.4	3.4	0.6	4.3	0.7	1.9	1.0	3.2
Staghorn sculpin	0.7	1.5	1.5	4.2	1.0	1.3	1.0	1.8
Petrale sole	0.8	2.7	<0.1	<0.1	-	-	0.5	1.7
Big skate	0.3	4.1	0.2	4.9	0.6	13.2	0.3	6.4
White surfperch	0.1	0.4	0.8	2.2	<0.1	<0.1	0.3	0.5
Spiny dogfish	0.3	3.3	<0.1	0.1	<0.1	0.3	0.2	2.2
Pacific herring	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1
Dover sole	0.2	1.0	-	-	-	-	0.1	0.6
Rex sole	0.2	0.6	-	-	<0.1	<0.1	0.1	0.4
Starry flounder	0.1	1.4	0.1	3.7	0.1	0.3	0.1	1.5
Lingcod	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1
Brown rockfish	0.1	0.8	-	-	<0.1	0.5	0.1	0.6
Pacific butterfish	0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
California tonguefish	<0.1	<0.1	0.2	0.1	<0.1	<0.1	<0.1	<0.1
Longfin smelt	-	-	0.2	<0.1	-	-	<0.1	<0.1
Hornyhead turbot	0.1	<0.1	0.1	0.2	<0.1	0.1	<0.1	<0.1
Pile surfperch	0.1	0.2	<0.1	<0.1	0.1	<0.1	<0.1	0.2
Pacific hake	0.1	1.6	-	-	-	-	<0.1	1.0
Brown smoothhound	<0.1	<0.1	<0.1	0.1	0.2	3.9	<0.1	1.0
Bat ray	-	-	<0.1	1.4	0.1	4.9	<0.1	1.4
Spotted cusk-eel	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pricklebreast poacher	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Rock sole	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Warty poacher	<0.1	<0.1	<0.1	<0.1	-	-	<0.1	<0.1
Leopard shark	-	-	-	-	<0.1	2.0	<0.1	0.5
Showy snailfish	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
California halibut	<0.1	0.6	<0.1	0.3	<0.1	0.2	<0.1	0.4
Longspine combfish	<0.1	<0.1	-	-	-	-	<0.1	<0.1
California skate	<0.1	0.2	-	-	-	-	<0.1	0.1
Pink surfperch	<0.1	<0.1	-	-	-	-	<0.1	<0.1
Rubberlip surfperch	-	-	<0.1	<0.1	-	-	<0.1	<0.1
Pygmy poacher	<0.1	<0.1	-	-	-	-	<0.1	<0.1
Pacific sandlance	<0.1	<0.1	-	-	-	-	<0.1	<0.1
Pacific electric ray	<0.1	0.1	-	-	-	-	<0.1	0.1
Green sturgeon	<0.1	0.1	-	-	-	-	<0.1	<0.1
Bay pipefish	-	-	<0.1	<0.1	-	-	<0.1	<0.1

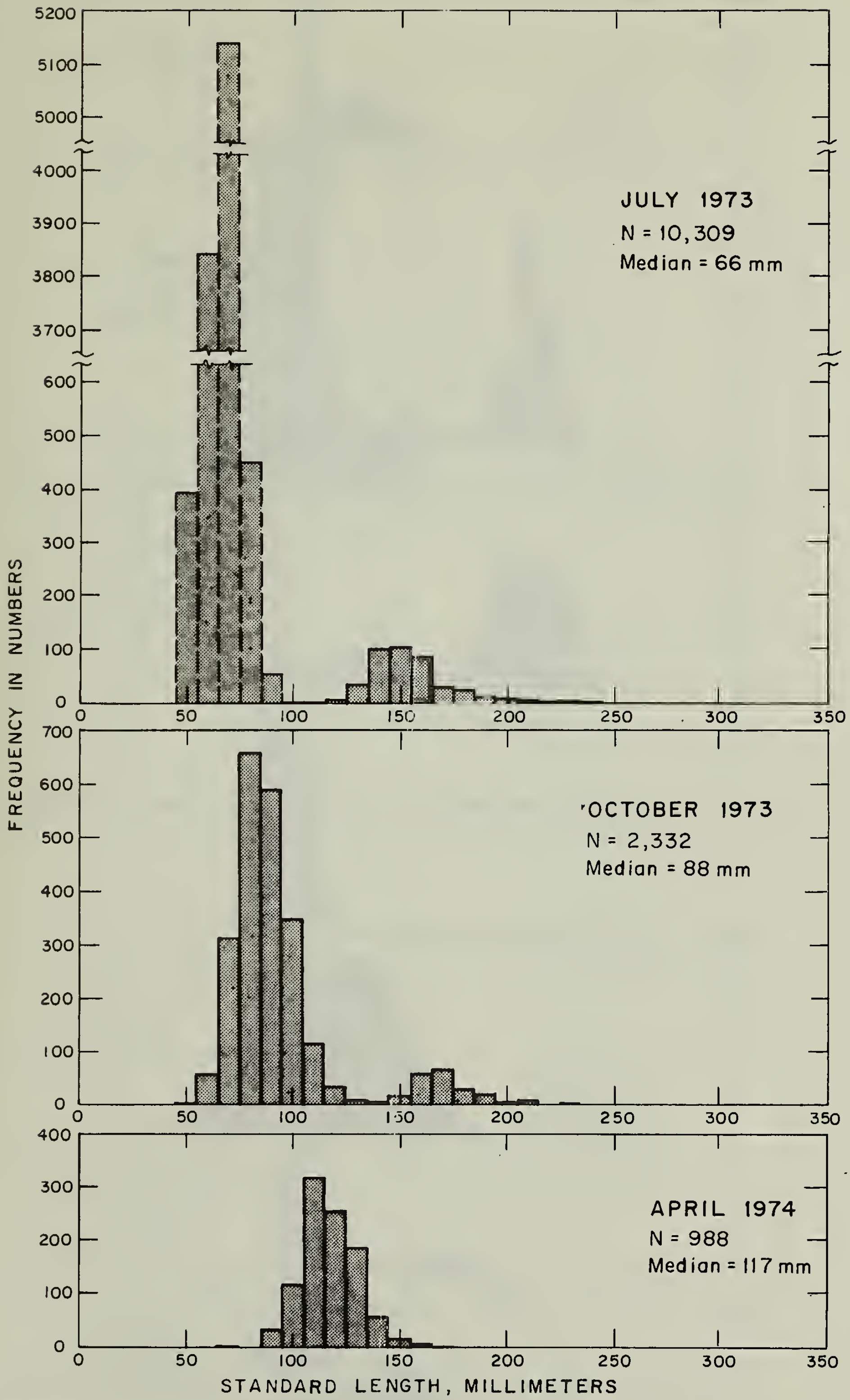

Fig. F-1 Length Frequency Distribution of Pacific Tomcod

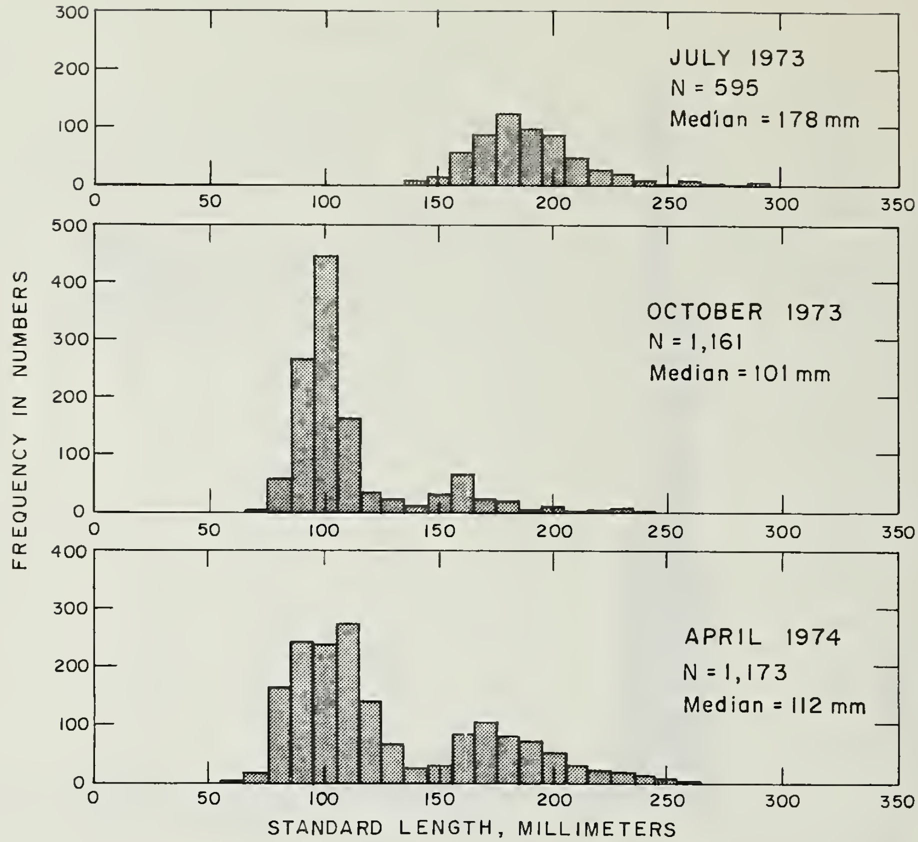

Fig. F-2 Length Frequency Distribution of Pacific Sanddab

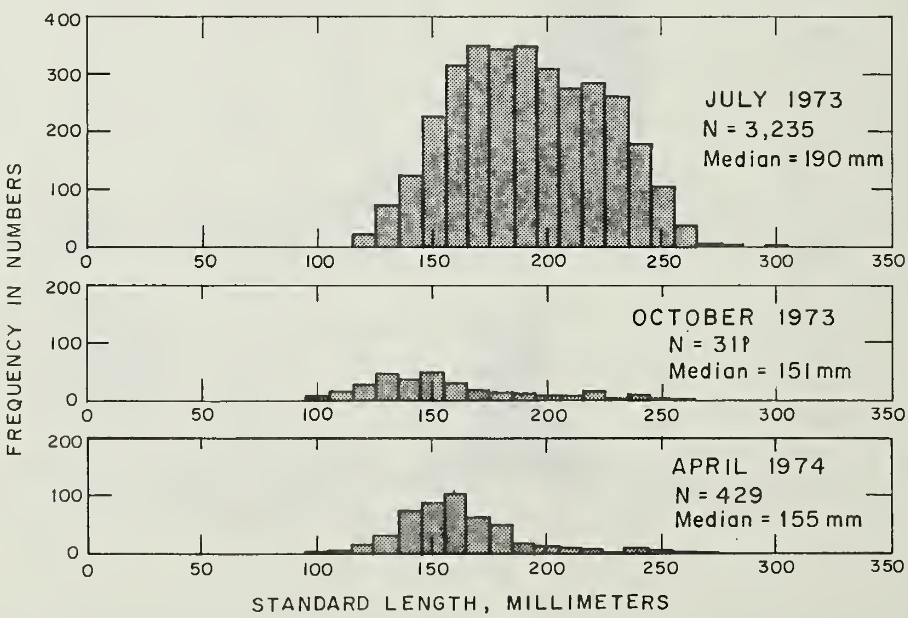

Fig. F-3 Length Frequency Distribution of White Croaker

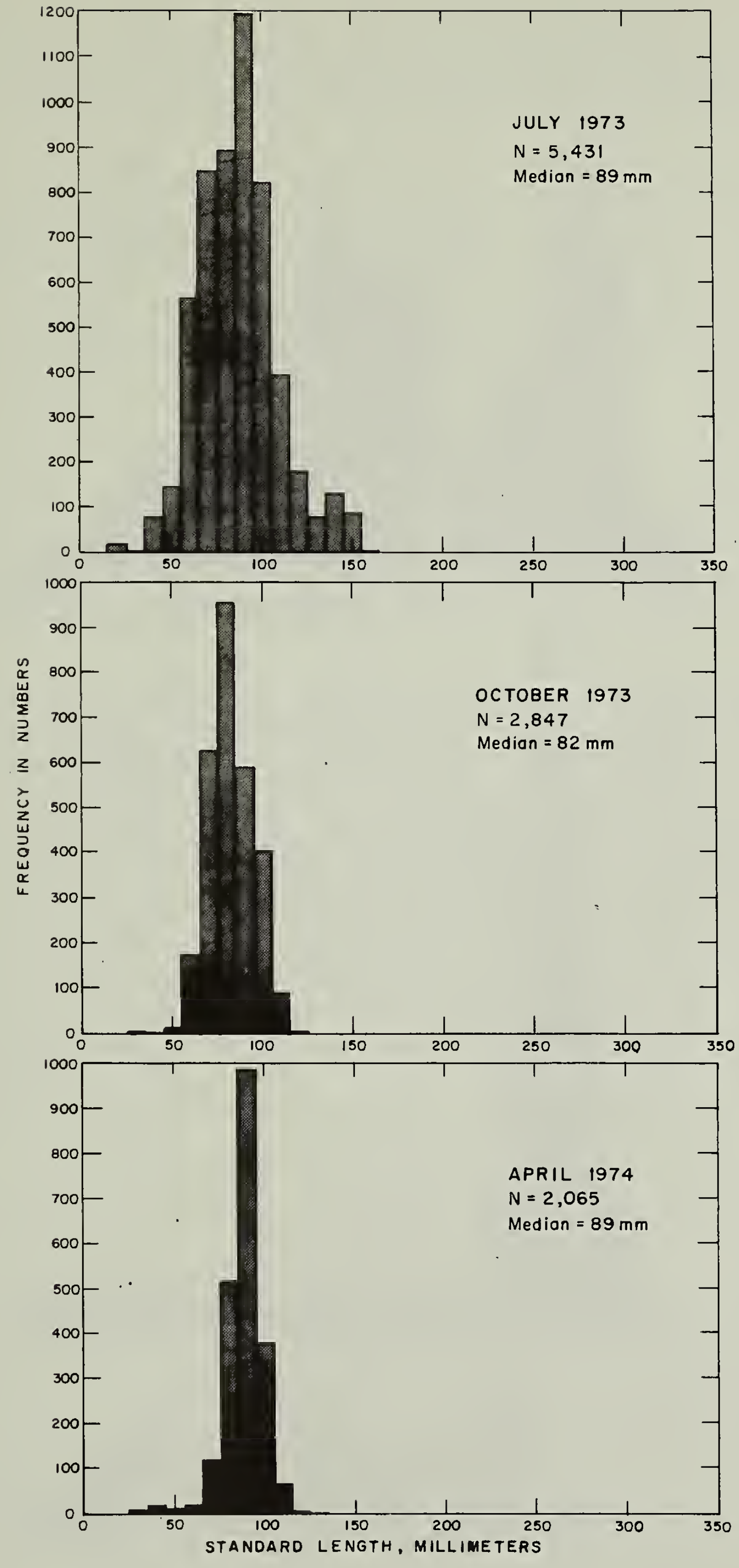

Fig. F-4 Length Frequency Distribution of Speckled Sanddab

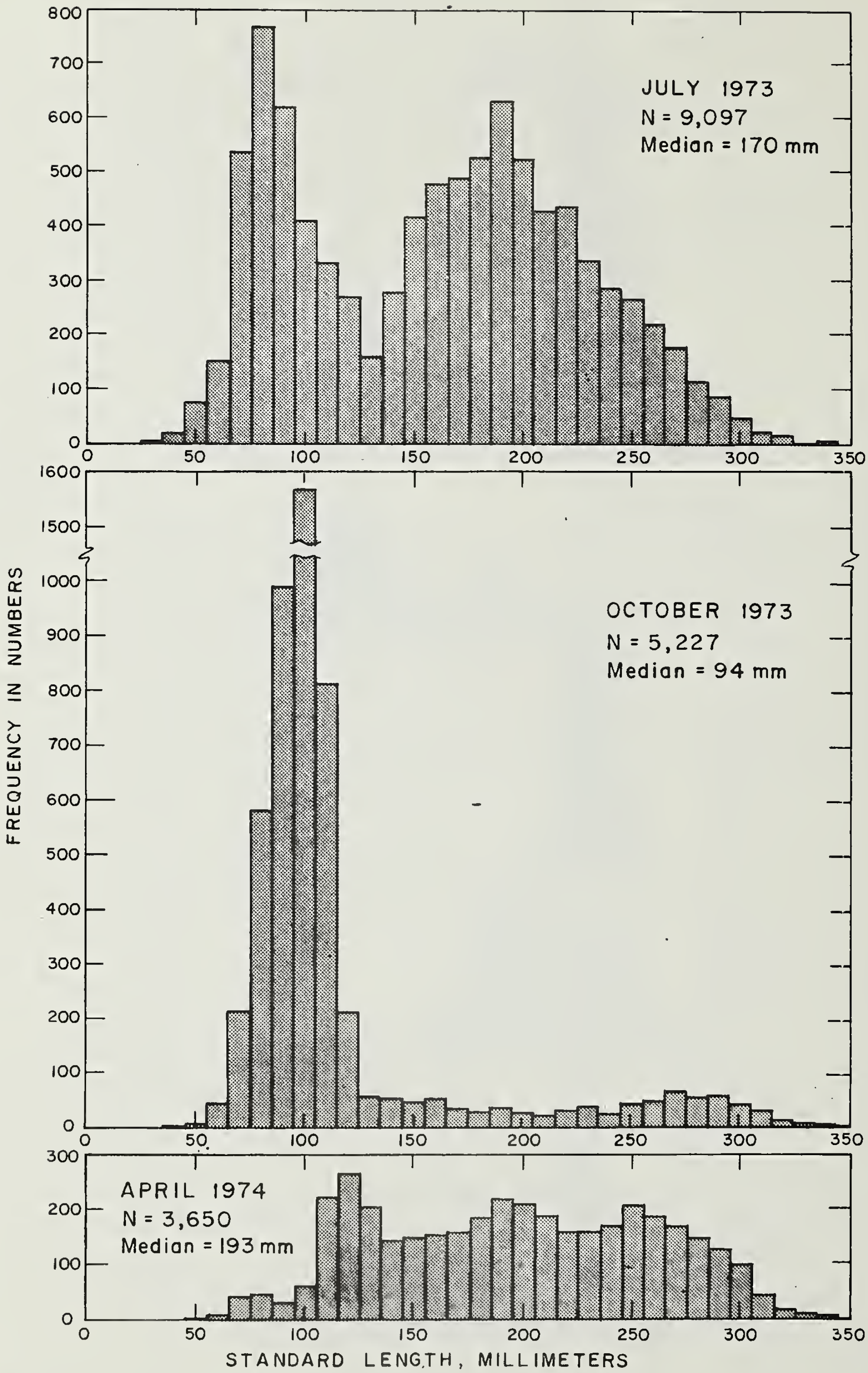

Fig. F-5 Length Frequency Distribution of English Sole

1974). The July 1973 catch was composed of large numbers of one year old and younger fishes as well as two and three year olds (Table F-3). In comparison, 84 percent of the October, 1973 catch were one year old and younger fishes, whereas the percent composition of the various age groups were roughly equal in April, 1974.

Table F-3. Percent Age Composition of English Sole, Gulf of the Farallones

Year Class[a]	July 1973	October 1973	April 1974
0-1	35	84	18
1-2	20	5	21
2-3	23	2	21
3-4	14	3	18
4-10	8	6	22

[a]The ages of fishes were estimated on the basis of data published by Smith and Nitsos (1969)

The predominance of young-of-the-year fishes in the English sole population found in the study area is not surprising since there appears to be a correlation between the size and age of fishes collected with respect to depth. The juveniles of this species are found more commonly inshore in the 20-29 fathom range (Demory, 1971; Ketchen, 1956). The distribution of fish-of-the-year is governed by the drift of the pelagic eggs and larvae but they are usually found in protected inshore areas, and bays and estuaries (Ketchen, 1956; California Department of Fish and Game, 1971). Spawning occurs off California between October and May, with peak spawning occurring in January and February. The incubation period of the eggs varies with temperature; hatching occurs in four days at 55.4 F or six days at 46.5 F. Larvae are 2.6 mm long when hatched and are pelagic for six to ten weeks. Thereafter, they metamorphose to their adult form and settle on the bottom (California Department of Fish and Game, 1971). These facts would explain the higher percentages of young-of-the-year English sole in the July and October survey catch.

The presence or absence of English sole larger than one year old is partly dependent on their state of maturity. Males may mature as early as two years of age, while most of them are mature at the age of three. Females seldom mature before they are three or four years old, and may still be immature at age five (Ehrhardt, 1973). Adults of this species are found inhabiting muddy or sandy bottoms in bays and estuaries to 300 fathoms but are more commonly encountered at depths of 30 to 70 fathoms (Alverson, 1960; Ketchen, 1956). As with other species in the family Pleuronectidae, the English sole presents evidence of interseasonal changes in bathymetric distribution (Demory, 1971). Tagging studies have indicated a seasonal pattern with respect to both direction and depth. Adults tagged in British Columbia by Forrester, 1959 and in Washington by Pattie, 1969 show a northerly migration in spring, a wide dispersion in summer, and a southerly migration in the early fall, which may reflect a post- and pre-spawning migration. Tagging studies by the Department of Fish and Game showed that most English sole tagged in the San Francisco area seemed to move north toward Eureka in the spring and summer and return in winter (Jow, 1969). Seasonal bathymetric migrations have also been observed for adults indicating a movement from shallower water in summer to deeper water in winter (Alverson, 1960; Ketchen, 1956; Demory, 1971).

The statistical reliability of inferences of seasonal variations based on the data obtained is limited, as the data represents only three trawl surveys done over a single 10 month period. The data obtained however, should prove useful as baseline information for reference in future monitoring.

APPENDIX G

An Evaluation of the Ecological and Economic Importance of Species of Fishes and Invertebrate Collected in San Francisco Bay in the Vicinity of the Outfall from the Southeast Water Pollution Control Plant

AN EVALUATION OF THE ECOLOGICAL AND ECONOMIC IMPORTANCE OF SPECIES OF FISHES AND INVERTEBRATES COLLECTED IN SAN FRANCISCO BAY IN THE VICINITY OF THE OUTFALL FROM THE SOUTHEAST WATER POLLUTION CONTROL PLANT

A trawl study was conducted during 1973 and 1974 in the vicinity of the present Southeast Water Pollution Control Plant outfall in San Francisco Bay offshore from the mouth of Islais Creek to determine what organisms inhabit the area. The ecological and economic importance of the species of fishes and invertebrates collected during this trawl has been evaluated based on a literature review of pertinent fishery information.

Table G-1. Number and Duration of Tows Made During the Trawl Survey in the Vicinity of Islais Creek, San Francisco Bay

	Trawl area		
Survey	I	II	III
December 3, 1973	2[a]	1[a]	1[a]
March 18, 1974	2[a]	2[a]	2[a]
May 30, 1974	2[a, b]	2[a, b]	1[b]
October 22, 1974	1[b]	4[b, c, d]	-

[a] 10 minute trawl
[b] 15 minute trawl
[c] 20 minute trawl
[d] 30 minute trawl

Trawl surveys were made in December 1973 and in March, May, and October 1974. Samples were collected with a 24-foot otter board trawl net. The decision on the number of trawls made and the areas sampled depended on the length of time it took to complete a minimum of three trawls and the presence or absence of snags (Table G-1). Figure G-1 shows the three areas sampled. Area I was selected because it included three habitat types: a rocky shoal; a mud shoal; and a portion of the dredged channel. This area was about 30 feet deep. Area II had a mud-shell substrate and was about 40 feet deep. Area III had a sand-shell substrate and was approximately 60 feet deep. Trawls were generally made in the direction of the current at about 1-2 knots. The length of time for the trawls varied between 10 and 30 minutes. Because this study was a qualitative rather than a quantitative study, variation in trawl time was not a controlling factor. Shorter trawls (10 minutes) were made in the inshore areas because of the increased possibility of snagging the net. Longer trawls of up to 30 minutes were made in deeper waters offshore where the bottom was less cluttered with debris.

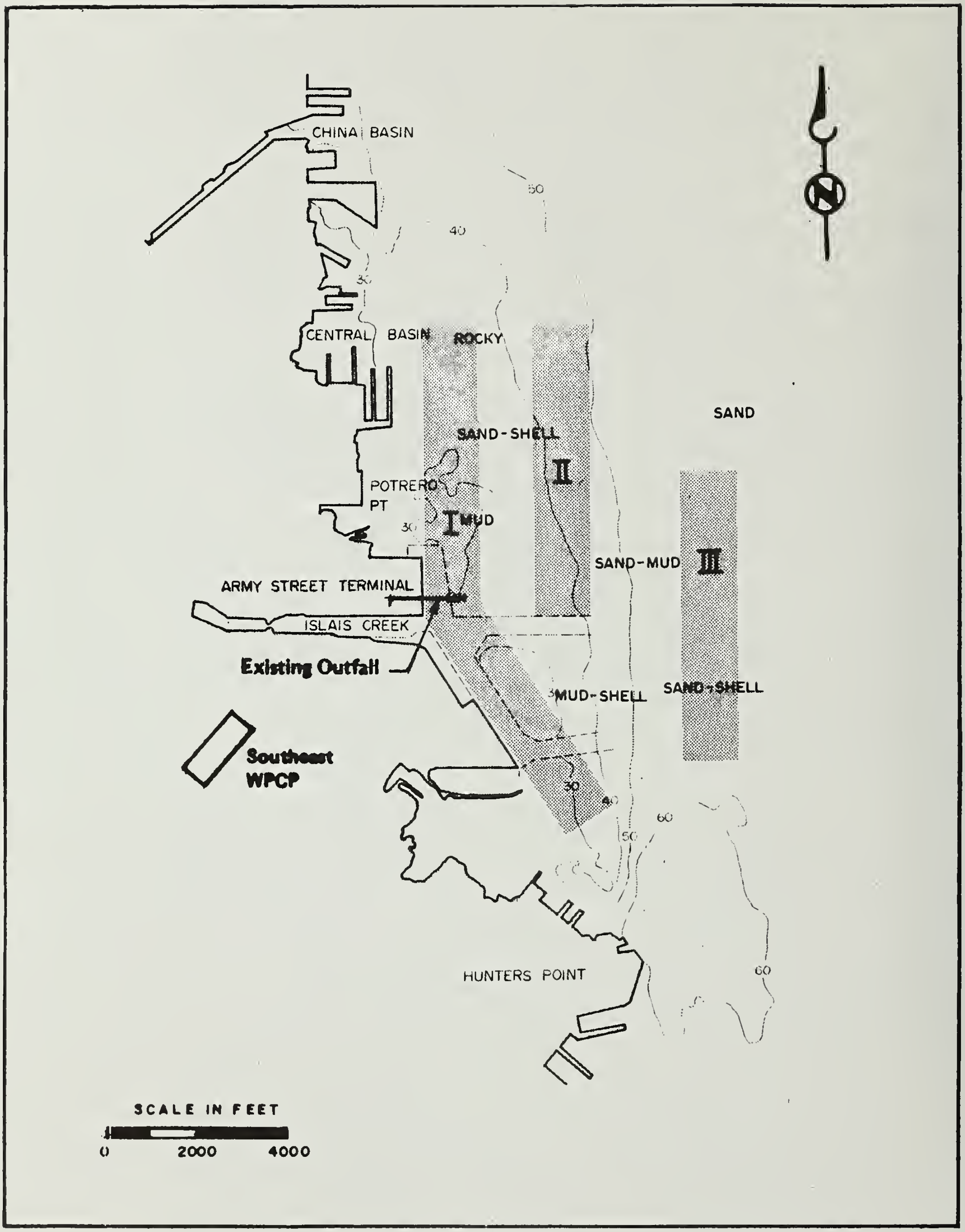

Fig. G-1 Trawl Sampling Areas in the Vicinity of the Southeast WPCP Outfall, San Francisco Bay

The trawl surveys resulted in the collection of 34 species of fishes (Table G-2) and approximately 14 species of invertebrates (Table G-3). The ecological and economic importance of the more commonly collected species are discussed below.

Table G-2. Common and Scientific Names of Fishes Collected from the Vicinity of Islais Creek, San Francisco Bay [a]

Scientific name	Common name
Family SQUALIDAE	
Squalus acanthias	Spiny dogfish
Family CARCHARHINIDAE	
Triakis semifasciatus	Leopard shark
Mustelus henlei	Brown smoothhound
Family TORPEDINIDAE	
Torpedo californica	Pacific electric ray
Family RAJIDAE	
Raja binoculata	Big skate
Family CLUPEIDAE	
Dorosoma petenense	Threadfin shad
Clupea harengus pallasii	Pacific herring
Family ENGRAULIDAE	
* Engraulis mordax	Northern anchovy
Family OSMERIDAE	
Allosmerus elongatus	Whitebait smelt
Spirinchus thaleichthys	Longfin smelt
Unidentified osmerids	Unidentified smelt
Family BATRACHOIDIDAE	
Porichthys notatus	Plainfin midshipman
Family OPHIDIIDAE	
Chilara taylori	Spotted cusk-eel
Family GADIDAE	
Microgadus proximus	Pacific tomcod
Family SYNGNATHIDAE	
Syngnathus leptorhynchus	Bay pipefish
Family SCORPAENIDAE	
* Sebastes auriculatus	Brown rockfish
Sebastes melanops	Black rockfish
Family HEXAGRAMMIDAE	
Ophiodon elongatus	Lingcod
Family COTTIDAE	
Leptocottus armatus	Staghorn sculpin
Artedius notospilotus	Bonyhead sculpin
Family SERRANIDAE	
Roccus saxatilis	Striped bass
Family SCIAENIDAE	
Genyonemus lineatus	White croaker
Family EMBIOTOCIDAE	
Rhacochilus toxotes	Rubberlip surfperch
Hyperprosopon argenteum	Walleye surfperch
* Cymatogaster aggregata	Shiner surfperch
Damalichthys vacca	Pile surfperch
Phanerodon furcatus	White surfperch
Family GOBIIDAE	
Lepidogobius lepidus	Bay goby
Acanthogobius flavimanus	Yellowfin goby
Family CYNOGLOSSIDAE	
Symphurus atricauda	California tonguefish
Family BOTHIDAE	
* Citharichthys stigmaeus	Speckled sanddab
Family PLEURONECTIDAE	
Hypsopsetta guttulata	Diamond turbot
* Parophrys vetulus	English sole
Platichthys stellatus	Starry flounder

* One of five species predominant in the catch.

[a] Common and scientific names taken from Miller and Lea, 1972.

Striped Bass

The striped bass is native to the Atlantic Coast and was introduced to the Pacific Coast in 1879. This species is one of the most important sport fishes in California, and San Francisco Bay and its associated tributaries is the center of its Pacific Coast fishery. Striped bass are concentrated in San Francisco Bay from July to November but this species can be caught there throughout the year (Moriguchi, 1973).

Only a single specimen was collected during this study (on the March 1974 survey in Area I) and was 194 mm long. This species is seldom collected with an otter trawl because it is a strong swimmer and can normally avoid capture.

Table G-3. Species of Macroinvertebrates Collected by Trawling in the Vicinity of the Southeast WPCP Outfall

Scientific Name	Common Name
brachyuran	Unidentified brachyuran
Busycotytus canaliculatus	Channeled whelk
Cancer antennarius	Rock crab
Cancer gracilis	Slender crab
Cancer magister	Dungeness crab
Cancer productus	Red crab
* *Crago franciscorum*	Bay shrimp
* *Crago nigricauda*	Blacktail shrimp
Crago nigromaculata	Blackspot shrimp
Heptacarpus spp.	Unidentified broken-back shrimp
mysidacean	Unidentified mysid shrimp
Pagurus spp.	Unidentified hermit crab
Pagurus hirsutiusculus	Hermit crab

* Species predominant in the catch

Large concentrations of striped bass have been reported within the study area and adjoining areas, especially in the vicinity of the Pacific Gas and Electric power plants at Potrero and Hunters Point (Pacific Gas & Electric Company, 1974; Wooster, 1968; Moriguchi, 1973; and Herald and Simpson, 1955). The results of these studies indicate that most of the bass in the study area are small, usually less than 510 mm. In the vicinity of the study area, the shore fishing effort of striped bass occurs at the above two areas as well as most of the piers along the waterfront and at the Hunters Point Naval Shipyard (Wooster, 1968). The skiff fishing effort is concentrated in a shoal area located 450 yards north of Pier 34, along the Alameda rockwall, and on both the east and west side of Yerba Buena Island (Moriguchi, 1973.

Adult striped bass have a well-defined annual migration in the Sacramento-San Joaquin River system. They begin their annual upstream spawning migration from the ocean and San Francisco Bay around November (Calhoun, 1952). Spawning takes place upstream from Pittsburg, especially in the Delta portion of the San Joaquin River and upstream from the Delta in the Sacramento River to above

its confluence with the Feather River (Farley, 1966). Evidence of spawning has been detected as far upstream as Colusa on the Sacramento River (Chadwick, 1965) and near the town of Patterson on the San Joaquin River (Woodhull, 1947). Most of the population spawns between April 5th and June 25th (Farley, 1966), but females with ripe eggs have been found between March and the first of August (Scofield, 1931). Radtke (1966) found that most bass spawned and had left the Delta by early June to early July. From the middle of June to the end of August, bass are concentrated in the marine and brackish-water areas in the lower bays, especially San Francisco Bay, and adjacent coastal waters. During September and October most of these fishes return to the Delta (Calhoun, 1952). Chadwick (1967) reported that since 1950 to 1952, the trend has been for increasing numbers of adult bass to spend more time in San Francisco Bay and the open ocean and less time in the Delta.

Young-of-the-year bass apparently have no well-defined migration patterns. Instead, their distribution appears to be a result of tidal currents which carry the eggs and larvae downstream (Clark, 1936). The egg and larval stages together last approximately 10 days (Albrecht, 1964). According to Kelley (1968), about 80 percent of these young fishes spend their first summer in one of the following three localities: eastern Suisun Bay; the Sacramento River upstream to about Isleton; or the San Joaquin River upstream to Venice Island, During years of high wet weather runoffs, larger proportions of small bass are found farther west in the Delta and in Suisun Bay (Chadwick, 1964). Young-of-the-year bass have been reported in San Francisco Bay by Herald and Simpson (1955), Kelley (1968), Wooster (1971), and Moriguchi (1973). Sasaki (1966) hypothesized a migration of young-of-the-year bass from the Delta through Suisun and San Pablo bays into San Francisco Bay as an explanation for the steady and major decline of these fishes during the fall season in the Delta.

Moriguchi (1973) hypothesized that there are two populations of striped bass in San Francisco Bay. One is a spawning population which migrates from the Delta into San Francisco Bay between May and August. These adult fishes remain in the bay until the end of November, when the majority return to the Delta. Some adult bass may remain in the bay as late as March, when there are large amounts of bait fishes in the bay, especially spawning herring. The second population is one of subadult bass which migrate from the Delta and remain in San Francisco Bay, primarily south of the San Francisco-Oakland Bay Bridge.

A food habit study of striped bass in San Francisco Bay was made in 1972 which gives some insight into the relative importance of forage species, at least with respect to this valuable game fish (Moriguchi, 1973). For the purpose of analyses, the author divided the bay into three subregions: south, central, and north bay. In the south bay, the most common of the 20 food items identified are, in descending order of occurrence: shiner surfperch, northern anchovy, and species of <u>Crago</u> shrimp (Table G-4). In San Francisco Bay overall, the northern anchovy was the most commonly found species; the shiner surfperch was second. Less frequently occurring were species of topsmelt and true smelts, species of <u>Crago</u> shrimp, the Pacific tomcod, species of sculpin-like fishes (both sculpins and gobies), the river lamprey, and the Pacific herring.

<u>Semi-Pelagic Fishes</u>

Approximately one-third of the fishes collected were semi-pelagic species. These included the northern anchovy, Pacific herring, whitebait smelt and longfin smelt. All four species form schools and at certain times of the year they can be found in San Francisco Bay in large numbers.

Table G-4. Contents of Striped Bass Stomachs Given as Frequency of Occurrence of Food Items per Month, South San Francisco Bay (Moriguchi, 1973)

Items	Frequency of Occurrence					Frequency of occurrence for 140 stomachs examined, percent
	Jul	Oct	Nov	Dec	Total	
Shiner surfperch	-	11	35	11	57	41
Northern anchovy	-	5	12	12	29	21
Bay shrimps[a]	-	7	12	7	26	19
Topsmelt	-	4	4	1	9	6
Bay pipefish	-	-	3	-	3	2
Bay goby	-	-	2	1	3	2
Unidentified fish	-	1	6	-	7	5
All other fishes[b]	-	4	6	5	15	11
All other invertebrates[c]	-	-	3	1	4	3
Empty stomachs	5	5	36	6	52	37
Number of stomachs examined per month	5	23	84	28	140	

[a] Under this heading are unidentified species of Crago, C. franciscorum, and C. nigricauda.

[b] Pacific herring, white surfperch, silver surfperch, staghorn sculpin, Pacific shad, river lamprey, whitebait smelt, showy snailfish, and unidentified gobiids and bothids.

[c] Upogebia pugettensis, Cancer productus, and unidentified nereids.

Northern Anchovy. The northern anchovy was the most commonly collected species and made up 24 percent of the total number of fishes collected in the study area. The majority (77 percent) of the anchovies were collected during the March 1974 survey. If, as assumed, these fishes were collected coincidentally with the raising and lowering of the net or at times when the net was not holding bottom, the relatively large numbers collected would indicate a sizable concentration of this species in the study area.

The number of anchovies collected during the surveys ranged from 4 to 276 fishes. This wide range was in part a result of incidental collection. Another possible explanation is that, since anchovies travel in schools, the number of fishes collected is dependent on the portion of the school sampled.

Anchovies spawn in inshore waters all year-round with a peak around February or May (Mais, 1974; Talbot, 1973). It has been speculated that anchovies may spawn in the bay, but no evidence of this has been found.

The importance of northern anchovy as a forage organism is well documented and is reflected by the existence of a local lampara net bait fishery for this species. They are netted in both the ocean and San Francisco Bay. Anchovies collected in

the bay are usually from central San Francisco Bay, since they are generally small in the south bay (Herald and Innes, unpublished). The length of the specimens collected in the study area ranged from 42 to 107 mm.

Frozen anchovy is the principal bait used for salmon locally. There is also a live anchovy bait industry for striped bass fishing.

Pacific Herring. Pacific herring were collected on every survey and were all fish-of-the-year. Their lengths ranged from 60 to 85 mm. San Francisco Bay is a known nursery for Pacific herring and is the principal spawning area for this species in California (Miller and Schmidtke, 1956). Adult herring enter and spawn in the bay between December and April (Scofield, 1918). Figure G-2 shows the areas in which herring have been reported to spawn (Skinner, 1962). The eggs can be found on rocks, algae, and pilings from the intertidal zone to six fathoms below the mid-tide mark (Miller and Schmidtke, 1956). During the summer and fall months, the Pacific herring constitute only a minor component in the diet of the striped bass. However, if the adult herring enter the bay before the late fall upstream migration of striped bass, they will probably constitute the bulk of the striped bass diet (Moriguchi, 1973).

Smelt. The white bait and longfin smelt are of minor importance in the commercial fisheries. They are sold as "Whitebait smelt" which includes at least four other species of the true smelt family Osmeridae (California Department of Fish and Game, 1971).

Flatfishes

Five flatfish species made up 27 percent (401 individuals) of the catch. Of these, only the speckled sanddab, English sole, and starry flounder were collected in any number.

Speckled Sanddab

The speckled sanddab was the most commonly collected of these species and was found on all surveys. This species is small; individuals more than 170 mm long are rare (Miller and Lea, 1973). The speckled sanddabs collected in the study area ranged in size from 50 to 100 mm and most were adults. This species has some importance as a forage organism.

English Sole

English sole was the second most numerous flatfish collected. It is common in the San Francisco Bay system, especially in San Pablo Bay (Kelley, 1966; Herald and Innes, manuscript, 1965). A trawl survey was done by PG&E (1973) at stations near the Hunters Point and Potrero power plants in San Francisco. English sole made up 46.3 percent of the 2,800 fishes collected in that survey.

Juvenile English sole are very common in the bay but adults are rarely found. Only 10 percent of the 113 specimens collected were mature. San Francisco Bay may be a spawning area for this species, but evidence of this has not yet been found. This species has pelagic eggs and larvae which may be carried into the bay from the open ocean by tidal action. The eggs hatch in about 90 hours and the larvae metamorphose to the adult form in six to ten weeks (California Department of Fish and Game, 1971).

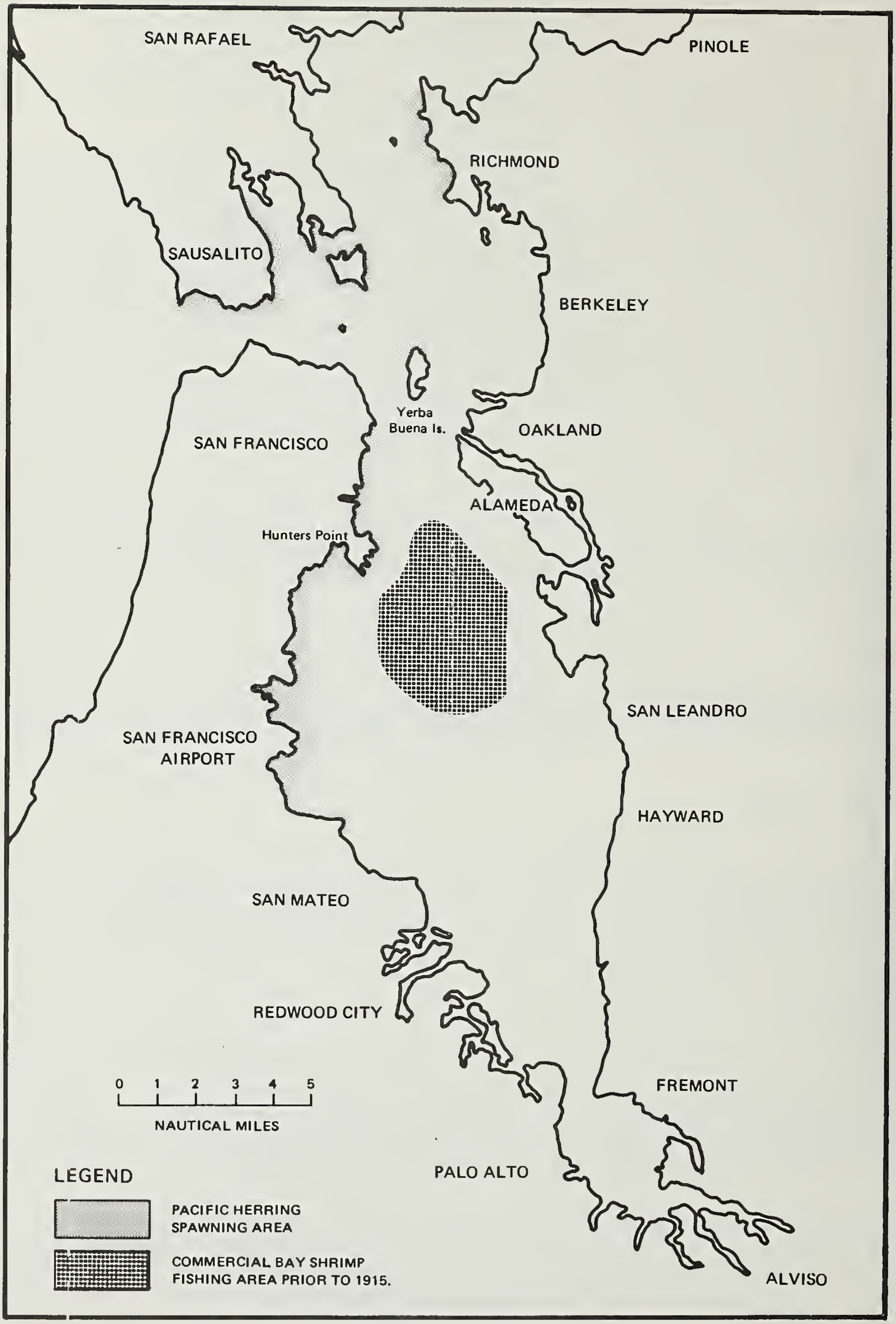

Fig. G-2 Areas Where Pacific Herring are Reported to Spawn and Commercial Bay Shrimp Fishing Areas Prior to 1915

The relative importance of San Francisco Bay as a nursery is difficult to assess, since no measure of the exchange between the bay and ocean populations has been made.

English sole have little economic importance in the bay although they were caught commercially there before 1890 (Skinner, 1962). However, landings of English sole in the ocean off of San Francisco were almost half (43 percent) of the total California catch of this species between 1961-1965 (Jow, 1969).

Starry Flounder

The starry flounder is very common in San Francisco Bay and is represented by both adults and juveniles. The spawning period for this species is between November and February, with a peak in January and February (Orcutt, 1950). The commercial importance of this species is minor.

Surfperches

Surfperches were represented in the catch by five species. Shiner surfperch was the most commonly collected. They were primarily adults ranging from 60 to 100 mm. This fish is important in the commercial live bait industry for striped bass fishing and is the second most common food item of striped bass in San Francisco Bay (Moriguchi, 1973). Pile surfperch and white surfperch were collected less frequently and ranged in size from 90 to 120 mm. Only two walleye surfperch and one rubber-lip surfperch were collected. Other species reported to be common in the study area are the black and striped surfperch (Herald and Simpson, 1955; Pacific Gas & Electric Company, 1973). All but the walleye surfperch are sold commercially in San Francisco (California Department of Fish and Game, 1971).

Sharks, Skates and Rays

Five species of elasmobranchii were collected in this survey: the brown smooth-hound (660 mm); leopard shark (840 mm); spiny dogfish (700 to 800 mm); big skate (410 mm); and Pacific electric ray (260 mm).

The three species of sharks represented in this survey are the most commonly collected sharks in San Francisco Bay (Herald and Innes, manuscript, 1965). This is based on catch data from the 1943 shark set line survey done by the California Department of Fish and Game in the north bay and on catch data from five of the Coyote Point shark fishing derbies (Herald and Ripley, 1951; Herald, 1953). The brown smoothhound comprised 58 percent of the catch in the DFG survey, whereas in the several Coyote Point shark derbies they comprised between 43 and 58 percent of the catch. The leopard shark was the second most common species in the catches, comprising 14 percent and between 23 and 46 percent, respectively. The spiny dogfish was third, comprising 23 percent and between 0 and 7 percent of the catches, respectively. All three species have some commercial value (California Department of Fish and Game, 1971).

The big skate is a relatively common species in the bay and also has some commercial value (California Department of Fish and Game, 1971). The Pacific electric ray is rarely collected in the bay, but it has been reported in the study area (Herald and Simpson, 1955).

Rockfish

Rockfish were represented by two species. The brown rockfish was relatively common and was collected on all surveys. The number of brown rockfishes collected may be biased relative to the other fishes since an effort was made to sample the rocky shoal in Area I (Fig. G-1) where known concentrations of this species occurs. Their size ranged from 50 to 200 mm and most of them were juveniles. The black rockfish, also juveniles, ranged in size from 41 to 65 mm. According to Herald and Innes (manuscript, 1965), San Francisco Bay may be an important nursery for many rockfish species.

Miscellaneous Species of Fishes

The threadfin shad is at times common in the bay, but only four specimens were collected. This species is of minor commercial importance in the bay as live bait for striped bass fishing, and is only used when northern anchovy and shiner surfperch are not available. The two other species found in the study area and collected commercially as bait for striped bass are the yellowfin goby and staghorn sculpin.

Species of Crago Shrimp

The San Francisco Bay shrimp fishery is dependent on a composite of several species: *Crago franciscorum*, *C. nigricauda* and to a lesser extent on *C. nigromaculata* and species of *Heptacarpis*. *Crago franciscorum*, the bay shrimp, comprises the bulk of the landings. At times, however, *C. nigricauda*, the blacktail shrimp, may be 50 percent or more of the catch in certain localities.

These shrimp have been fished for commercially in San Francisco Bay since 1869 (California Department of Fish and Game, 1971). The first commercial fishermen were Italians, who primarily sold their catch as fresh shrimp. In 1871, the Chinese introduced the Chinese shrimp net and began exporting large quantities of dried shrimp to China (Skinner, 1962). Because of the tremendous loss of juvenile commercial fishes with these shrimp nets and the potential depletion of the shrimp stock, the state legislature placed closed seasons on shrimp fishing (1901 and 1909), made it unlawful to export dried shrimp (1905), and prohibited the use of shrimp nets (1911). In 1914, the shrimp beam trawl was introduced into the north San Francisco Bay fishery and this method of capture is still being used there (Skinner, 1962).

Records of the yearly shrimp landings have been kept since 1915. Peak landings of over 3 million pounds were made in 1929 and 1935 and since then have declined steadily (California Department of Fish and Game, 1971). From 1940 to 1957 the landings averaged 700,000 pounds, but by 1959 the catch dropped to 35,000 pounds. Since there was little market demand for fresh shrimp from 1960 to 1964, the fishery was virtually eliminated (California Department of Fish and Game, 1971).

In 1965, a new fishery was developed to supply both live and frozen shrimp as bait for striped bass and sturgeon. The price to the fisherman was sufficiently high to provide an economic return for small landings and therefore, landings increased from 7,000 pounds in 1965 to 47,000 pounds in 1968 (California Department of Fish and Game, 1971).

The general locations of shrimp fishing areas prior to 1915 are shown in Fig. G-2. Since then the south San Francisco Bay fishery virtually collapsed. Herald and Innes

(manuscript, 1965) attributed part of the decrease in the south bay fishery at that time to the restrictions placed on activities in this area by war time naval operations at Hunters Point. They also speculated that the construction of Treasure Island in 1938 might have affected bottom conditions and limited the size of the south bay shrimp grounds. In the last two years, shrimp fishing has started up again in south San Francisco Bay at the mouth of Coyote Creek and in Alviso slough (Dan Owyand, commercial shrimp fisherman, 1975). The fishing grounds in upper San Francisco Bay and San Pablo Bay still maintain an existing fishery which in late fall extends to northern Suisun Bay.

Bay Shrimp

The bay shrimp, Crago franciscorum, ranges from southeastern Alaska to San Diego. Locally, they are reported to be found from San Francisco Bay to lower Suisun Bay throughout the year, and extend up the lower San Joaquin River in the fall, to within 15 miles of Stockton. They were the most commonly collected shrimp species in the study area and were primarily collected during the May 1974 survey.

The main breeding season for bay shrimp extends from December to May or June, although egg-bearing females are found throughout the year (Israel, 1936). These shrimp migrate toward the ocean as the spawning season approaches; the eggs are hatched in highly saline water. The larval stages are thought to be planktonic. Immature juveniles are found most commonly in shallow water of reduced salinity. As they grow, they gradually move into deeper water and are found in greatest quantity at depths around 15 feet on shell-mud or mud bottoms, the latter being preferred. This species matures at the end of the first year and thereafter is not collected. Whether they die after one year or leave the bay is not known.

Blacktail Shrimp

The blacktail shrimp, Crago nigricauda, ranges from Alaska to Baja California, (Israel, 1936). This species is apparently less tolerant of freshwater than C. franciscorum and is found only as far upstream as Suisun Bay in the fall (Israel, 1936). It is, however, locally abundant in the bay.

The blacktail shrimp comprised 21 percent of the shrimp catch in the study area. According to Dan Owyang (commercial shrimp fisherman, personal communication, 1975), this species is collected in greater quantities at depths less than 15 feet. Crago franciscorum and C. nigricauda have similar life histories, except C. nigricauda breeds chiefly from April through September.

Dungeness Crab

Immature Dungeness crabs, Cancer magister are reported to be abundant year-round in both San Francisco and San Pablo bays (Skinner, 1962). Schmitt (1921) reports their presence from Carquinez Strait to Point San Mateo.

Two specimens of this species were collected, one each on the March and May 1974 surveys. The former was an adult female, 115 mm (shoulder width), the other was a juvenile male, 15 mm. Two additional crabs were observed clinging to the net on the March survey, but they were lost before they could be brought aboard. These two specimens were also approximately 115 mm. The collection

of adults (greater than 100 mm) is reported as being rare (Skinner, 1962). Kelley (1966) reported the size range of the Dungeness crabs he collected in San Pablo and Suisun Bays as being 40 to 140 mm. The reason for a lack of adults in the bay is not known. San Francisco Bay may be a nursery ground for this species and upon maturity these crabs may move towards ocean waters to reproduce.

No evidence of egg laying in San Francisco Bay by female Dungeness crabs has ever been found. Pelagic eggs and larvae may be carried into the bay from the open ocean with the large tidal action at the Golden Gate. If this is what happens, it would explain the large numbers of juvenile Dungeness crabs that inhabit the bay. In laboratory studies conducted by Poole (1966), the total time required to develop from the egg to the first adult form of the Dungeness crab was 111 days.

This discussion is not to be construed as being definitive. At least 93 species of fishes have been reported to occur in the vicinity of the study area (Table G-5). Many of these species are as important, if not more important, than the species discussed. These fishery data have been compiled to aid in future monitoring efforts and to contribute to the growing knowledge of the fisheries of San Francisco Bay.

Table G-5. Species Reported by Several Investigators to be Found in South San Francisco Bay between the Bay Bridge and the San Francisco Airport

Species[a,b]	Bonnot, 1932	Herald and Simpson, 1955	Herald and Innes, 1958	Aplin, 1967	PG&E, 1973	This study
Pacific lamprey		x	x			
Western river lamprey	x		x			
Sevengill shark	x	x	x	x		
Spiny dogfish		x	x	x		x
Pacific angel shark			x			
Common thresher			x			
Leopard shark	x	x	x	x	x	x
Gray smoothhound					x	
Brown smoothhound		x		x		x
Soupfin shark			x			
Pacific electric ray	x	x	x	x		x
Big skate	x		x	x		x
California skate		x				
Longnose skate		x				
Batray	x	x	x	x		
Green sturgeon				x		
Threadfin shad				x	x	x
American shad			x	x	x	
Pacific herring	x	x	x	x	x	x
Pacific sardine	x	x	x	x		
Northern anchovy	x	x	x	x	x	x
King salmon		x		x		
Steelhead trout				x		
Surf smelt		x	x			
Whitebait melt		x	x			x
Night smelt				x		
Longfin smelt	x	x	x	x		x
Plainfin midshipman	x	x	x	x		x
Spotted cusk-eel		x	x			x
Pacific hake			x			
Pacific tomcod	x	x	x	x	x	x
Jacksmelt		x		x	x	
Topsmelt		x	x	x	x	
Tubesnout		x				
Threespine stickleback		x				
Bay pipefish	x	x	x	x		x
Black-and-yellow rockfish		x				
Brown rockfish	x	x	x	x	x	x
Grass rockfish		x				
Black rockfish	x	x	x			x
Yellowtail rockfish		x				
Bocaccio	x	x	x			
Lingcod		x	x	x		x
Whitespotted greenling				x		
Kelp greenling		x				
Rock greenling				x		
Cabezon		x	x	x		
Brown Irish lord		x				
Red Irish lord				x		
Staghorn sculpin	x	x	x	x	x	x

Table G-5. Species Reported by Several Investigators to be Found in South San Francisco Bay between the Bay Bridge and the San Francisco Airport (continued)

Species (continued)	Bonnot, 1932	Herald and Simpson, 1955	Herald and Innes, 1958	Aplin, 1967	PG&E, 1973	This study
Buffalo sculpin		x	x			
Padded sculpin			x	x		
Bonyhead sculpin			x	x		x
Smoothhead sculpin						
Rosylip sculpin			x			
Pricklebreast poacher				x		
Pygmy poacher			x	x		
Showy snailfish	x	x	x	x		
Slipskin snailfish		x	x			
Striped bass		x	x	x	x	x
Jack mackeral		x				
White croaker	x	x	x	x	x	x
Rubberlip surfperch		x	x	x	x	x
Black surfperch		x	x	x	x	
Redtail surfperch		x				
Walleye surfperch		x		x	x	x
Shiner surfperch	x	x	x	x	x	x
Rainbow surfperch		x		x		
Striped surfperch		x	x	x	x	
Dwarf surfperch		x		x	x	
Silver surfperch					x	
Pile surfperch		x	x	x	x	x
White surfperch		x	x	x	x	x
Wolf-eel		x	x			
Rock prickleback		x				
Saddleback gunnel	x	x	x	x		
Pacific sandlance			x	x		
Longjaw goby		x			x	
Bay goby		x	x	x		x
Yellowfin goby						x
Arrow goby			x			
Pacific butterfish		x	x	x		
California tonguefish				x		x
California halibut			x	x		
Curlfin turbot		x	x	x		
Hornyhead turbot				x		
Diamond turbot				x	x	x
Sand sole	x		x	x		
English sole	x	x	x	x	x	x
Starry flounder	x	x	x	x	x	x
Pacific sanddab		x	x		x	
Speckled sanddab			x	x	x	x
Dover sole			x			

[a]The bigmouth sole, speckledfin midshipman, and yellowfin croaker were also reported to have been collected in trawl surveys by Pacific Gas and Electric Company (1973). According to Miller and Lea (1972), the most northerly range for the bigmouth sole is Monterey Bay, and Pt. Conception for the others. No specimens were saved.

[b]Common names taken from Miller and Lea (1972).